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JOURNAL OF SCIENTIFIC INSTRUMENTS

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X-RAY TUBE WITH DETACHABLE ELECTRODES SUITABLE FOR CRYSTAL ANALYSIS.

By E. A. OWEN, M.A., D.Sc., and G. D. PRESTON, B.A. National Physical Laboratory.

[*MS. received, 25th May,* 1926.]

ABSTRACT. A modification of the Shearer X-ray tube is described in which sealing-wax joints are replaced by india-rubber washers pressed against a flanged porcelain tube, and certain modifications are made in the internal construction.

SEVERAL types of gas-filled X-ray tube have been employed in X-ray spectroscopy. Of these the one extensively used in this country is that designed by Shearer, which is a modification of an earlier design by Müller and employed originally by him for the examination of the spectra of the elements. This tube gives an intense beam of X-rays and is very suitable for use in X-ray spectroscopic analysis. A description of the tube will be found in *X-Rays and Crystal Structure*, by W. H. and W. L. Bragg, pp. 34 and 295.

The chief drawback to the tube is the fact that three sealing-wax joints must be made to render it air-tight, two of which are between metal and glass of about 2 inches diameter. Apart from the time it takes to ensure that these joints are air-tight, there is the attendant risk of cracking the glass in the operation. The same risk attends the operation of removing the glass tube for cleaning which must be done periodically, as the tube ceases to function after a certain thickness of material has been sputtered on the walls.

The tube which we are about to describe was designed with a view to overcoming these difficulties. The glass cylinder is replaced by porcelain and the joints are rendered air-tight by rubber washers. The electrodes differ also in design from those of the original Shearer tube. Fig. 1 shows in plan drawn to scale the construction of the tube. The cathode C consists of a hollow sphere for water cooling, soldered to a brass cap into which is screwed a rod of aluminium A covered with a brass tube. A rubber washer R about half an inch wide fits into a recess in this brass cap. A short brass collar B_1 screws into the cap in the inside of the tube and protects the washer. A flange F at the end of the porcelain cylinder bears on the rubber washer and is drawn up firmly against it by means of a screw collar S fitted on the outside of the porcelain and separated from the flange at its end by a greased fibre washer G.

We found this method of pressing the porcelain against the rubber washer satisfactory. We have used with success another somewhat simpler design and possibly this might be preferred when the applied voltage on the tube is not high. It is easy to make and to manipulate and consists simply of four screws fixed into the brass plate to which the sphere is soldered. These screws pass through holes in a split brass ring fitting over the porcelain cylinder and having a rubber ring between it and the flange at the end of the porcelain. Four spherical nuts draw the ring and the cathode together, thus securing an air-tight joint. Either method proves quite satisfactory. The latter is simpler in construction, but there is

a tendency to spark at the nuts when the voltage is raised above a certain value. This probably could be obviated by using a longer porcelain tube.

A similar joint is made at the other end of the porcelain tube. The dimensions of the various parts are readily obtained from the diagram. The brass collar B_2 attached to the anticathode is longer than the collar B_1 at the cathode end. The purpose of this collar (B_2), in addition to protecting the rubber washer from the discharge, is to shield the cathode from the metal ring on the outside of the porcelain cylinder. If it is too short, sparking is liable to occur at the ring with the consequent danger of a breakdown of the insulation.

The anticathode end is made from one piece of metal. A channel is provided for water circulation which serves to cool the rubber washer. It was not found necessary to provide water cooling for the window. The window W is covered with thin aluminium foil, about 0·001 in. thick, mounted on thin celluloid (photographic film) and the joint between it and the metal surface rendered air-tight by means of sealing-wax. Another rubber washer joint, to replace this wax joint, is at present in course of construction.

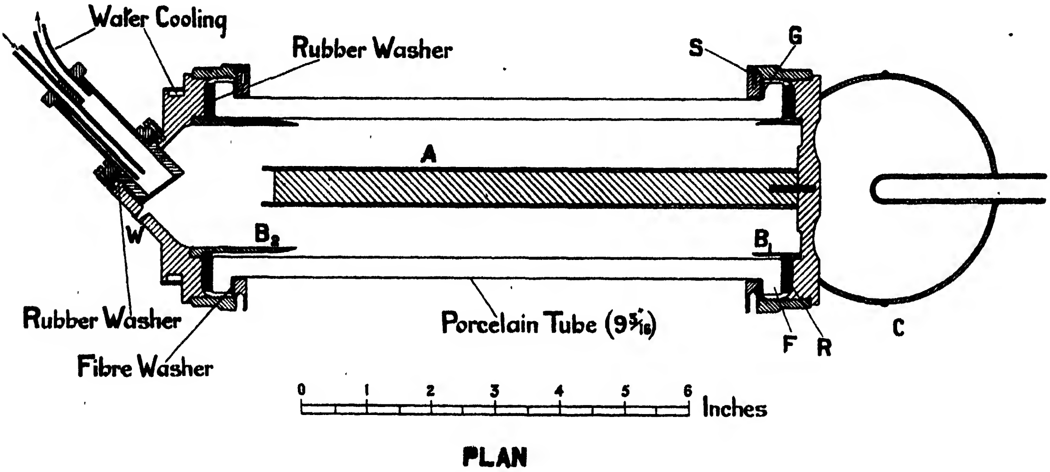

Fig. 1

The target is of simple design and the joint between it and the main body of the metal is again rendered air-tight with a rubber washer. The end of the target is about one millimetre thick and is cooled by a rapid flow of cold water. The water cooling tubes are fixed into a cap which screws into the target. The same cap is used with all the targets which are interchangeable.

The design of the anticathode end is such as to bring the surface of the target as near as possible to the lip of the brass collar extending into the tube.

The tube is mounted in a suitable stand which is shown in elevation in Fig. 2. When the tube is operating the ebonite support P is swung into the horizontal position about the hinge at the bottom end. To dismantle the tube the support P is raised into position and the collar D unscrewed, thus freeing the porcelain tube from the anticathode which is held on a brass pillar fixed to the base-board; this in turn is fixed to the table. The porcelain tube is moved sideways in its stand on the slide E. Afterwards the collar S is unscrewed and the tube removed by slightly turning the stand N which is capable of rotation about the nut H. The operation of dismantling and reassembling the tube occupies only a few minutes. For this reason it was possible to carry out experiments on the most favourable dimensions of different parts of the tube. Particular attention was paid, for instance, to the length of the collar B_2 (Fig. 1), the most suitable length for the tube described here being shown in the diagram. Another investigation carried out with the tube was the

variation of the size of focal spot with different lengths of cathode. It was found that the focal spot increased in size as the cathode was shortened. The focus of the tube, the dimensions of which are shown in Fig. 1, was quite sharp and it emitted a powerful beam of X-rays. When the cathode was increased in length beyond about 21 cm. the tube worked unsteadily. A cathode 19 cm. long proved very satisfactory.

The life of the tube depends upon how quickly the walls get sputtered with material from the cathode. We have had a tube running for 180 milliampere hours without needing attention as regards cleaning. The cleaning operation is, however, so easily performed that it does not matter whether the tube requires cleaning every day. The porcelain cylinder is

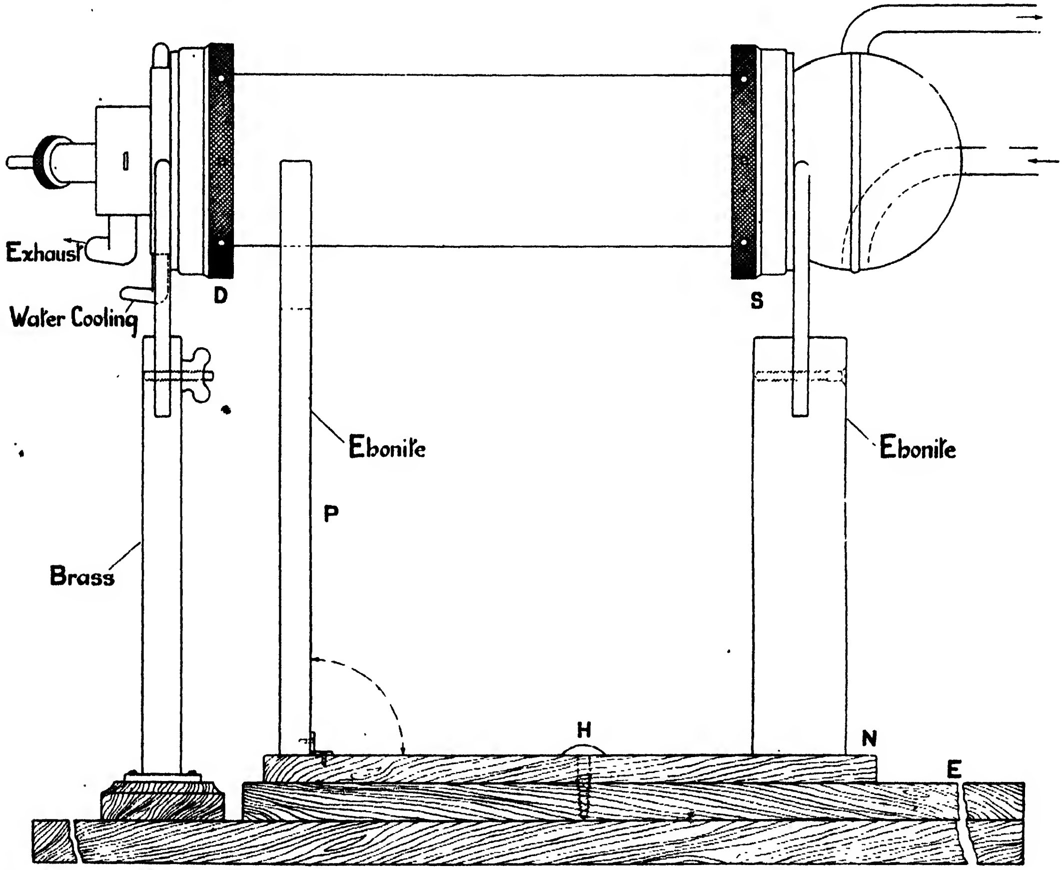

Fig. 2

removed, as already explained, and the sputtered layer cleaned off with a swab of cotton waste moistened with nitric acid. The walls are then washed with another swab dipped in water and dried. This operation occupies about five minutes and X-rays are produced in less than fifteen minutes from the moment the dismantling of the tube is commenced.

High vacuum was obtained with a Backhurst-Kaye metal diffusion pump backed by a Geryk oil pump.

It is important with this type of tube that proper precautions are taken to shield against stray radiation. We may point out that the thick porcelain is advantageous in this connection, as it absorbs a greater percentage of the radiation than a thin walled glass tube.

We are indebted to Mr W. Turl for his assistance in designing the tube and the care and attention he has given to its construction.

THERMAL AMPLIFICATION OF GALVANOMETER DEFLECTIONS.

By PROF. A. V. HILL. From the Department of Physiology and Biochemistry, University College, London.

[*MS. received, 27th May*, 1926.]

ABSTRACT. Moll and Burger have proposed a method, employing a vacuum thermo-relay, *for the amplification of galvanometer movements.* This, or an analogous method employing radiation thermopiles, is extremely satisfactory and allows very high sensitivities to be obtained with moving coil galvanometers.

In a recent paper (1) Moll and Burger have described a thermo-relay for amplifying galvanometer deflections. During the last four months I have made an extensive trial of this method of amplification, in connection with the problem of measuring the heat produced by a nerve during stimulation. Full details are given elsewhere (2). The method, however, is of such general application, and is so effective, that readers of the *Journal* may be glad to hear of it.

If the edge of a beam of light, reflected from a galvanometer mirror, be allowed to fall upon the junctions of a radiation thermopile, lying behind a narrow slit, the E.M.F. produced being balanced, preferably by the same source of light acting upon a similar thermopile, then a small deflection of the galvanometer will produce a relatively large change in the E.M.F. which can be measured on a second galvanometer. The E.M.F. in the thermopile depends upon the intensity of the light, but since the counter E.M.F. does the same, no displacement of zero will result from fluctuations in the illumination. If a stable moving coil galvanometer be used for the primary it is possible to amplify its movements many times, and since comparatively little lag is introduced by the thermopile the speed of response depends mainly upon that of the galvanometers.

In my earlier experiments I employed Moll thermopiles made by Messrs Kipp of Delft, balancing the E.M.F. in a linear thermopile, illuminated by the beam from the galvanometer, against the E.M.F. from a surface thermopile exposed at a distance, with an adjustable diaphragm in front of it, to the same source of light. With this, employing two A. and M. moving-coil galvanometers by the Cambridge Instrument Company, it was possible to reach, on a scale at 3 metres distance, a sensitivity of 1 mm. $= 5 \times 10^{-12}$ amp., an amplification of about one hundredfold. The readings were slow, but only 1 sec. in the deflection time was to be attributed to the thermopile. In later experiments I employed a vacuum thermo-relay, most kindly given me by Messrs Kipp. In this a single couple of constantan-manganin-constantan strip, about 0·5 mm. wide and 0·001 mm. thick, is mounted in a vacuum and exposed over its central portion to a vertical band of light from the primary galvanometer, concentrated if desired by a cylindrical lens. A deflection in one direction warms one junction and cools the other, a deflection in the other direction does the reverse, so that the device is differential in its action, and in the central position no E.M.F. is produced. The deflection of a second galvanometer connected to the thermocouple is directly proportional, over a comparatively wide range, to that of the first one: and the amplification is very high, 250-fold or more if desired. This thermo-relay owes its sensitivity to the absence of air around it, together with its extreme thinness and slow heat-conduction. In consequence of these factors it is rather slower than the coupled thermopiles (which work in air and reach a maximum very rapidly) and is stated to require 3 secs. to give its full reading. It

is, however, extremely simple and convenient to erect and use and requires little adjustment: while its sensitivity should give it a wide range of usefulness. Its amplification moreover is uniform within wider limits than that of the other arrangement.

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(1) Moll and Burger. *Phil. Mag.* **50** (1925) 624.
(2) Downing, Gerard and Hill. *Proc. Roy. Soc.* B, **100** (1926) 223.

APPARATUS FOR MEASURING THE MECHANICAL CONDITION OF PAPER.

By H. C. BOOTH, A.R.C.Sc.
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[*MS. received*, 1st *May*, 1926.]

ABSTRACT. An apparatus is described for measuring the mechanical condition of paper. It was primarily designed for the estimation of the extent of the deterioration that had taken place in the paper dielectric of an electric cable under various conditions of use. The principle of the method consists in measuring the energy required to tear through a small strip of the sample. The tear is made by a wire of specified size actuated by a falling weight, and the paper is held in a special form of clamp.

Introduction

In arriving at an estimate of the safe limit of temperature to which a cable, insulated with paper, may be safely exposed, it is desirable to have some means of determining the mechanical condition of the paper from tests made on samples which under certain circumstances may not be more than one or two square centimetres in size. On account of the smallness of the specimen the ordinary tensile test which is very frequently employed is not well adapted to the purpose. Moreover, where the sample to be measured consists of a short length of impregnated paper forming part of the spiral covering of an insulated cable which has been for some time exposed to a high temperature, a test on the tensile strength is not only very difficult to carry out, but is likely to be unreliable, since the actual breaking strength of the length tested may be rendered altogether indeterminate, if, as frequently happens, a small or incipient break occurs at any part of it. In the process of removing such a sample from the covering, straightening it out, and preparing it for the test, it is often difficult to avoid injuring the paper. A further disadvantage of this method of test is that for each separate determination a fairly considerable length of paper is required, and as a series of measurements must always be made in dealing with a substance like paper, in order to eliminate the effect of local variations, this makes it necessary that a considerable length should be available.

Another method of testing has also been adopted in which the principle involved is the measurement of the energy required to make a straight tear of specified length. Although applicable in the case of new and unimpregnated paper it is not well adapted to measurements on short lengths of paper taken from a cable dielectric, on account of the difficulty of preparing the sample and ensuring that the tear should take place in the proper direction and not run to the edge of the strip. It seems reasonable to suppose, however, that a method of estimating the mechanical condition of paper depending upon the measurement of the energy required to tear a given length, rather than the force required to rupture a given width, is likely to be more consistent. It will be less influenced by local variations, since it essentially consists in the measurement of an integrated effect. This principle has, there-

fore, been adopted in the apparatus to be described; but the method of tearing the paper has been substantially modified and made specially applicable to the case where only short lengths of paper taken from an actual cable dielectric are available.

Description of the Apparatus

In the apparatus designed to make use of this principle the sample to be tested is held in a double pair of flat clamps, the essential construction of which is shown in Fig. 1, and is passed through a wire loop or stirrup (Fig. 2) which is free to move in the space between the clamps. (The wire of which the loop is made is preferably of about 0·05 inch diameter as this size was found by trial to give the most consistent results.) The loop is connected

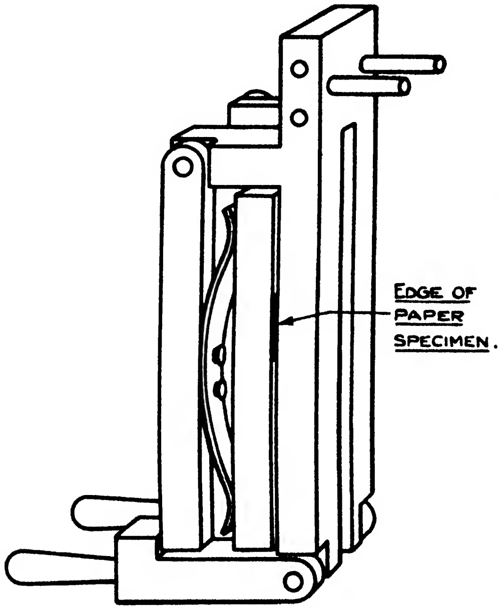


Fig. 1

Fig. 2

by means of a flexible cord to the lower end of a pendulum which is raised to a horizontal position, and which on being released draws the wire loop through the paper. The pendulum swings with negligible friction on a horizontal axis. The connecting cord is so attached that after the loop has torn through the paper it becomes detached from the pendulum; and the latter is free to continue its swing and rises to a height which will vary according to the amount of energy which has been expended in tearing the paper.

The general appearance of the apparatus is shown in Fig. 3. *W* is the pendulum when raised to the initial horizontal position. The lever *O* is rigidly connected to the same axis as *W*; and, as the latter swings forward, it comes into contact with and pushes forward the indicating pointer *P* which is prevented by a slight frictional control from over-shooting or moving back from the maximum position. The divisions over which the pointer moves are equi-spaced along a tangential straight line and not along the arc of a circle. They thus directly indicate proportional amounts of energy. The scale is mounted on a sliding plate, and the zero is set to the point to which the pointer moves when the pendulum swings from the initial horizontal position freely and without tearing any paper. The effects of any small residual frictional losses are thus allowed for. The tangential distance by which

the pointer fails to reach this zero position when the loop has been torn through a paper sample is thus a measure of the energy expended, and the scale intervals can be directly calibrated in terms of some convenient unit.

In view of the unavoidable divergencies which present themselves among individual results in testing such a material as paper, it is always advisable that a series of readings should be taken and the results given as a mean value. In taking such a series a length of the sample is placed in the clamps in such a position that the wire loop will be pulled through it at right angles to the length. After each individual test the paper strip is then

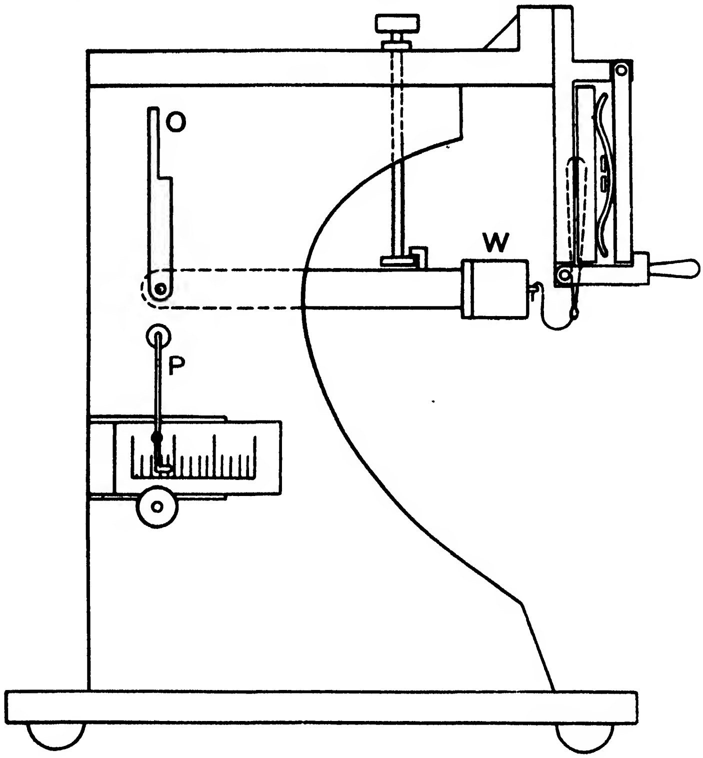


Fig. 3

METHOD OF USE

advanced a short distance in order to obtain a fresh part, and in this way a series of ten or more readings can, if necessary, be obtained from one or two inches of paper.

The amount of the energy expended will also depend upon the breadth and thickness of the strip. Where only comparative tests are required, as for instance in estimating the progressive mechanical deterioration due to continued exposure to heat, it is better, if possible, to arrange that the successive tests should be made on portions of the same strip. Where this cannot be done an allowance must be made for the effect of any difference in the breadth or thickness. It was found by actual tests on a large number of samples of the same paper of different widths, that the energy expended was closely proportional to the width torn through over a fairly wide range. In a similar way allowance can be made for the effect of thickness; but it is always advisable in taking a series of comparative tests to use paper which is originally of the same thickness, since it is more difficult to estimate the effect of varying thickness than to allow for the effect of different widths.

An example of the type of results obtained with a sample of paper taken from the insulating cover of an electric power cable is appended.

The values are expressed in millions of ergs. (*a*) represents the zero reading of the machine which was taken at frequent intervals to check the setting of the scale; (*b*) readings after tearing through the paper; (*c*) the thickness of the sample in the neighbourhood of the tear as measured in mm. with a micrometer.

The width of the sample was $1\frac{1}{2}$ in. = 3·81 cm.

												Mean value
Zero	(*a*)	0·98	—	0·98	—	0·98	—	0·98	—	—	—	0·98
Instrument reading	(*b*)	1·84	2·06	2·03	2·05	2·04	2·00	2·14	2·08	1·90	2·00	$2{\cdot}01_4$
Thickness	(*c*)	$0{\cdot}09_5$	$0{\cdot}07_3$	$0{\cdot}09_0$	$0{\cdot}10_4$	$0{\cdot}09_6$	$0{\cdot}07_3$	$0{\cdot}09_4$	0·088	0·100	$0{\cdot}07_7$	0·089

Mean $(b - a) = 1{\cdot}03_4$ millions of ergs.

The work done therefore is $1{\cdot}034 . 10^6$ ergs for a width of 3·81 cm. which is equivalent to $0{\cdot}272 . 10^6$ ergs per cm. The specific value taking account of the thickness would be $0{\cdot}272/0{\cdot}0089 = 30{\cdot}5 . 10^6$ ergs per cm. of width and for a thickness of 1 cm.

The apparatus has been developed in the course of researches carried out at the National Physical Laboratory on behalf of the Electrical Research Association.

THE USE OF A RESONANT SHUNT WITH AN EINTHOVEN STRING GALVANOMETER. By S. BUTTERWORTH, M.Sc., A. B. WOOD, D.Sc., and E. H. LAKEY, B.Sc.

[*MS. received, 2nd June,* 1926.]

ABSTRACT. The paper gives the theory of the action of a resonant shunt when used with an Einthoven string galvanometer, and records are given showing agreement with theory. In order to use a resonant shunt as a damping device, the following rules must be observed. The shunt constants must be so chosen that the free electrical oscillation in the shunt when short circuited is an exact copy of the free mechanical oscillation of the string when short circuited. This fixes the values of LC and of R/L for the shunt.

The absolute value of L depends upon the degree of damping required, small inductances yielding large dampings. For practically undamped strings, critical damping is obtained if the coil reactance at the resonant frequency of the string is equal to one-half the resistance of the string.

If the geometric mean between the coil reactance and the critical resistance of the string is equal to one-half the actual resistance of the string, the degree of damping is the same as if the galvanometer were on short circuit. In this case also the combination of galvanometer and shunt possesses no back electromotive force.

1. The use of a resonant shunt for bringing about critical damping of the fibre of an Einthoven galvanometer is discussed by Mr J. T. Irwin in his book on *Oscillographs* (Arnold). In illustration of his method, Irwin takes the case of a galvanometer in which the fibre is of silvered glass 3 μ in diameter. The mechanical damping of this fibre is already considerable and the extra damping required to produce the dead beat condition is therefore small.

In certain experiments carried out by one of the writers, use was made of an Einthoven galvanometer having a phosphor bronze fibre of diameter 15 μ and tuned to a frequency of 1600 cycles per second. As the damping of this fibre on open circuit was very small and the instrument was far from being critically dead beat even when an ordinary shunt of very low resistance was employed, an attempt was made to use Irwin's conditions to bring about the requisite critical damping by means of a resonant shunt. It was found that this condition could be attained but that the value of the resistance necessary in the arm of the shunt did not satisfy the conditions given by Irwin.

An examination of Irwin's theory shows that he has neglected the back electromotive force produced by the motion of the string. In the following work this back electromotive force is taken into account and conditions analogous to those of Irwin are obtained. It appears that in the case of a metallic fibre this back electromotive force is vitally important, and it is only when there is a large resistance in series with the instrument that Irwin's conditions become valid.

An investigation is also made in regard to the effective impedance of the combination, and it is shown that with the use of a suitable inductance the combination acts as if no back electromotive force is present. This should prove a valuable property when the instrument is used in a circuit of low impedance as then the relation between any applied variable electromotive force and the corresponding current assumes its simplest possible form.

2. For simplicity, the string of the galvanometer will be treated as a system of one degree of freedom. This simplification is valid so long as we are dealing with alternating currents of which the frequency does not approach the first overtone of the string. Under these conditions, the deflection y of the string is related to the current i flowing through the string by the equation

$$(\alpha D^2 + \beta D + \gamma) y = Ai \qquad \text{......(1)},$$

in which α, β, γ, A are instrumental constants and D is the time operator d/dt.

Regarding the string as of negligible inductance and of resistance r, the fall in potential along the string is ri due to resistance and ADy due to its motion, as the power supplied per unit of current is equal to the force per unit current (A) multiplied by the velocity of the string.

In these formulae the deflection y is understood to be the deflection of the central point and to include any optical magnification, the instrumental constants being suitably chosen.

If, now, the string is shunted by a resistance R, an inductance L and a capacity C in series, and if the current through the shunt be i' while the total current is I, we have

$$i + i' = I \qquad \text{......(2)},$$

$$ri + ADy = \left(LD + R + \frac{1}{CD}\right) i' = v \qquad \text{......(3)}.$$

On eliminating i, i' between (1), (2) and (3) the relation between the deflection and external current becomes

$$[\{LCD^2 + (R + r) CD + 1\} (\alpha D^2 + \beta D + \gamma) + A^2CD^2] y$$
$$= A (LCD^2 + RCD + 1) I \qquad \text{......(4)}.$$

As is usual with equations of this type, D may be treated as an algebraic operator, and we see that equation (4) will reduce to an equation of the type of (1) if the time operator acting on the current is a factor of the time operator acting on the deflection. It may be shown that this reduction may only be brought about in the case in which the resonance frequency of the shunt is equal to that of the string; that is $\gamma/\alpha = 1/LC = \omega_0^2$ say.

3. Assuming equality of the two resonance frequencies, it is convenient to alter the notation as follows: put

$$\omega_0 t = \xi$$

so that

$$D = \omega_0 \cdot \frac{d}{d\xi} = \omega_0 D_\xi,$$

and let

$$\frac{R}{2\omega_0 L} = \rho, \quad \frac{r}{2\omega_0 L} = \sigma, \quad \frac{\beta}{2\omega_0 \alpha} = a, \quad \frac{A^2 C}{\alpha} = K^2 \qquad \text{......(5)}.$$

Then (4) becomes

$$[\{D_\xi^2 + 2(\rho + \sigma) D_\xi + 1\} (D_\xi^2 + 2aD_\xi + 1) + K^2 D_\xi^2] y = \frac{A}{\gamma} (D_\xi^2 + 2\rho D_\xi + 1) I \quad \text{......(6)},$$

or on writing the biquadratic operator in terms of its two quadratic factors,

$$(D_\xi^2 + 2\mu D_\xi + 1)(D_\xi^2 + 2\nu D_\xi + 1)\, y = \frac{A}{\gamma}(D_\xi^2 + 2\rho D_\xi + 1)\, I \qquad \text{......(7)},$$

in which

$$\mu + \nu = \rho + \sigma + a,\ \mu\nu = a(\rho + \sigma) + K^2/4 \qquad \text{......(8)},$$

that is μ and ν are roots of the quadratic equation

$$\chi^2 - (\rho + \sigma + a)\,\chi + a(\rho + \sigma) + K^2/4 = 0 \qquad \text{......(9)}.$$

Under the special condition $\mu = \rho$, equation (7) reduces to

$$(D_\xi^2 + 2\nu D_\xi + 1)\, y = \frac{A}{\gamma} I \qquad \text{......(10)},$$

or, reverting to the original notation,

$$\alpha D^2 + \left(\alpha \frac{r}{L} + \beta\right) D + \gamma \Big\} = AI \qquad \text{......(11)}.$$

This only differs from equation (1) in its damping factor, the damping term β being increased by an amount $\alpha r/L$. Hence if the condition $\mu = \rho$ can be satisfied, the effect of the resonant shunt for all forms of current is merely to increase the mechanical damping without affecting the sensitivity in any other way.

4. The condition that equation (11) shall be true is got by putting $\mu = \rho$ in (8) and then eliminating ν. Thus we find that the condition is $\sigma(\rho - a) = K^2/4$ or, by (5),

$$\frac{R}{L} = \frac{\beta + A^2/r}{\alpha} \qquad \text{......(12)}.$$

This simply means that the free decay of the electrical disturbance in the resonant shunt when short circuited shall be an exact copy of the free decay of the mechanical disturbance in the galvanometer when short circuited.

Condition (12) determines only the time constant of the inductance. To fix the inductance we can choose a suitable degree of damping. For example, if we wish to obtain a critically dead beat motion we must make (by (11))

$$\frac{r}{L} + \frac{\beta}{\alpha} = 2\omega_0 \qquad \text{......(13)}.$$

5. Although a critically dead beat condition is a desirable quality it may sometimes be better to choose the inductance from other considerations. In circuits of low impedance it is often desirable to use an instrument which will produce the minimum amount of current distortion, and this end will be attained if we can make the effective back electromotive force of the whole system negligible without greatly reducing its sensitivity. If v be the potential difference across the instrument terminals we find, from equations (1), (2), (3) and (5),

$$v = \frac{rI\,(D_\xi^2 + 2\rho D_\xi + 1)\{D_\xi^2 + (2a + K^2/2\sigma)\, D_\xi + 1\}}{(D_\xi^2 + 2\mu D_\xi + 1)(D_\xi^2 + 2\nu D_\xi + 1)} \qquad \text{......(14)}.$$

This reduces to the simple form $v = rI$ if we can make $\mu = \rho$ and $\nu = a + K^2/4\sigma$ simultaneously. With the help of the former condition, the latter condition may be replaced by $\sigma = K/2$. Remembering that if R_c be the ordinary critical resistance of the string and if δ be the logarithmic decrement per half period on open circuit,

$$\frac{\beta}{2\alpha\omega_0} + \frac{A^2}{2\alpha\omega_0 R_c} = 1,\ \frac{\beta}{2\alpha\omega_0} = \frac{\delta}{\pi} \qquad \text{......(15)},$$

we find that the condition $\sigma = K/2$ yields

$$2\omega_0 L = r^2/R_c\left(1 - \frac{\delta}{\pi}\right) \qquad \text{......(16)}.$$

L, then, is the value of the inductance to use in order to make the combination behave as an instrument possessing no back electromotive force.

It may be shown that with this inductance the damping is the same as if the instrument were short circuited, for in the short circuit case the added damping factor is

$$\frac{A^2}{\alpha r} = 2\omega_0 R_c\left(1 - \frac{\delta}{\pi}\right)\Big/ r = \frac{r}{L} \qquad \text{......(17)}$$

by (16), and this is the same as the added damping factor in equation (11).

Since the critical resistance of an Einthoven string is inversely proportional to the frequency of tuning of the fibre, equation (16) shows that the inductance required is independent of the string tension when, as is usually the case, the open circuit log. dec. is small.

It is obvious that the resulting damping may be either over or under dead beat according to the state of the possible short circuit damping. For slack fibres this condition is the over dead beat case, and a reduction in the damping may be brought about by a resistance in series in the instrument branch. Combining (17) with (12) (the condition that μ shall be equal to ρ) we find that this condition assumes the simple form $(R - r)/L = \beta/\alpha$. Usually β/α is so small that it will be sufficient to make $R = r$. With the same approximation and with the string tension so low that the critical resistance is greater than the instrument resistance the condition that the combination shall be critically dead beat and at the same time have zero back electromotive force is

$$R = r = R_c = 2\omega_0 L \qquad \text{......(18).}$$

6. *Determination of Instrumental Constants.* The string resistance and the resonant frequency present no difficulty. We further require the values of β/α and A^2/α. These are conveniently obtained from the logarithmic decrements of the free oscillations with various non-inductive circuit resistances. Thus if the deflection is reduced to one-half in n oscillations when the string frequency is f and the external resistance is R,

$$\frac{\beta}{\alpha} + \frac{A^2}{\alpha(R+r)} = \frac{f}{n}\log_e 4 = 1{\cdot}386\frac{f}{n} \qquad \text{......(19).}$$

Thus β/α and A^2/α are found by plotting f/n against $1/(R+r)$.

7. *Free motion of String Galvanometer at "Break" of External Circuit.* We have now shown that when certain conditions are satisfied the resonant shunt acts simply as if increasing the mechanical damping. In order, however, to determine how critical the necessary adjustments must be, it is useful to consider the more general case in which the only condition is that the free electrical frequency of the shunt is equal to that of the string. Let there be a steady current of strength I flowing so that the central deflection of the string is $Y = AI/\gamma$ and the shunt condenser is charged to a potential difference rI. When the external circuit is broken, the string current falls to zero instantaneously, but the deflection remains Y and its rate of change DY is zero because of the inertia of the string. This latter condition and the condition of zero string current makes the initial P.D. across the instrument, and therefore across the shunt, zero. But the P.D. across the condenser is rI, so that this must be balanced by the P.D. developed by the rate of increase of the current in the inductance L of the shunt. Calling this current i' and the string deflection y we therefore have for our initial conditions

$$y = Y,\ Dy = 0,\ i' = 0,\ Di' = \frac{rI}{L} = \frac{r\gamma}{LA}\cdot Y \qquad \text{......(20).}$$

Changing the variable t to $\xi = \omega_0 t$ and making use of (5) and (9) these equations become

$$(D_\xi^2 + 2\mu D_\xi + 1)(D_\xi^2 + 2\nu D_\xi + 1)\, y = 0 \qquad \text{......(22),}$$

$$(D_\xi^2 + 2aD_\xi + 1)\, y = Ai'/\gamma \qquad \text{......(23).}$$

The solution of (22) is

$$y = A_1 e^{-\alpha_1 t} + A_2 e^{-\alpha_2 t} + A_3 e^{-\alpha_3 t} + A_4 e^{-\alpha_4 t} \qquad \text{......(24)},$$

in which

$$\left.\begin{aligned} \alpha_1 &= \mu + \sqrt{\mu^2 - 1}, & \alpha_3 &= \nu + \sqrt{\nu^2 - 1} \\ \alpha_2 &= \mu - \sqrt{\mu^2 - 1}, & \alpha_4 &= \nu - \sqrt{\nu^2 - 1} \end{aligned}\right\} \qquad \text{......(25)},$$

and A_1, A_2, A_3 and A_4 are determined from the initial conditions.

The corresponding solution of (23) is

$$\frac{A}{\gamma} i' = \mu_1 A_1 e^{-\alpha_1 t} + \mu_2 A_2 e^{-\alpha_2 t} + \mu_3 A_3 e^{-\alpha_3 t} + \mu_4 A_4 e^{-\alpha_4 t} \qquad \text{......(26)},$$

in which

$$\mu_r = \alpha^2{}_r - 2a\alpha_r + 1 \qquad \text{......(27)}.$$

The initial conditions (20) give as the equations for A_1, A_2, A_3 and A_4,

$$A_1 + A_2 + A_3 + A_4 = Y \qquad \text{......(28)},$$

$$\alpha_1 A_1 + \alpha_2 A_2 + \alpha_3 A_3 + \alpha_4 A_4 = 0 \qquad \text{......(29)},$$

$$\mu_1 A_1 + \mu_2 A_2 + \mu_3 A_3 + \mu_4 A_4 = 0 \qquad \text{......(30)},$$

$$\mu_1 \alpha_1 A_1 + \mu_2 \alpha_2 A_2 + \mu_3 \alpha_3 A_3 + \mu_4 \alpha_4 A_4 = 2\sigma Y \qquad \text{......(31)},$$

to solve these it is convenient to write

$$\begin{aligned} \alpha_1 A_1 &= \tfrac{1}{2}(P + Q), & \alpha_3 A_3 &= \tfrac{1}{2}(R + S), \\ \alpha_2 A_2 &= \tfrac{1}{2}(P - Q), & \alpha_4 A_4 &= \tfrac{1}{2}(R - S) \end{aligned} \qquad \text{......(32)}.$$

Then with the help of (25) and (27) we find, from (29) and (30),

$$\left.\begin{aligned} P + R &= 0 \\ (\mu - a) P + (\nu - a) R &= 0 \end{aligned}\right\} \qquad \text{......(33)}.$$

Thus $P = R = 0$, and then, from (28) and (31),

$$\left.\begin{aligned} \sqrt{\mu^2 - 1}\, Q + \sqrt{\nu^2 - 1}\, S &= -Y \\ (\mu - a)\sqrt{\mu^2 - 1}\, Q + (\nu - a)\sqrt{\nu^2 - 1}\, S &= -\sigma Y \end{aligned}\right\} \qquad \text{......(34)},$$

or, on solving for Q, S and using (8),

$$Q = \frac{(\rho - \mu)\, Y}{(\mu - \nu)\sqrt{\mu^2 - 1}}, \qquad S = \frac{(\rho - \nu)\, Y}{(\nu - \mu)\sqrt{\nu^2 - 1}} \qquad \text{......(35)}.$$

Substituting these values in (24) and converting to hyperbolic functions, the formal solution of our problem is

$$y = \frac{Y}{\mu - \nu}\Big[(\mu - \rho)\, e^{-\mu\xi}\left(\cosh\sqrt{\mu^2 - 1}\,\xi + \frac{\mu}{\sqrt{\mu^2 - 1}}\sinh\sqrt{\mu^2 - 1}\,\xi\right)$$
$$- (\nu - \rho)\, e^{-\gamma\xi}\left(\cosh\sqrt{\nu^2 - 1}\,\xi + \frac{\nu}{\sqrt{\nu^2 - 1}}\sinh\sqrt{\nu^2 - 1}\,\xi\right)\Big] \qquad \text{......(36)}.$$

8. *Types of Free Motion.* Equation (36) shows that the free motion of the string at "break" consists, in this more general case, of two superposed damped motions, and that the special condition obtained previously is brought about by reducing the amplitude of one of these motions to zero.

So long as μ and γ have real values, either of these damped motions has properties similar to those for the unshunted case, each motion being capable of being over dead beat, critically dead beat or oscillatory. The form (36) holds directly for the over dead beat case. If either motion becomes oscillatory (which occurs when μ or ν is less than unity) the correct equation is obtained by replacing the hyperbolic functions by circular functions and $\sqrt{\mu^2 - 1}$ by $\sqrt{1 - \mu^2}$.

In the critically dead beat case (μ or $\nu = 1$) the motion assumes the form $e^{-\xi}(1 + \xi)$.

The solution (36) fails when $\mu = \nu$ which is the border case between real and complex values of μ and ν. The appropriate solution is then obtained from (36) by multiplying one of the damped motions by $\mu - \nu$ and then differentiating with respect to μ (or ν). Thus we get the following equations for this case:

$\mu > 1$.

$$y = Ye^{-\mu\xi}\left[\cosh\sqrt{\mu^2 - 1}\,\xi\left\{1 + \frac{(\mu - \rho)\xi}{\mu^2 - 1}\right\} + \sinh\sqrt{\mu^2 - 1}\,\xi\left\{\frac{\mu}{\sqrt{\mu^2 - 1}} - \frac{\mu - \rho}{(\sqrt{\mu^2 - 1})^3}\,\xi\right\}\right]$$

$\mu < 1$. ......(36 a).

$$y = Ye^{-\mu\xi}\left[\cos\sqrt{1 - \mu^2}\,\xi\left\{1 - \frac{(\mu - \rho)\xi}{1 - \mu^2}\right\} + \sin\sqrt{1 - \mu^2}\,\xi\left\{\frac{\mu}{\sqrt{1 - \mu^2}} + \frac{\mu - \rho}{\sqrt{1 - \mu^2}}\,\xi\right\}\right]$$

$\mu = 1$. ......(36 b).

$$y = Ye^{-\xi}\{1 + \xi + \tfrac{1}{3}(1 - \rho)\,\xi^3\} \qquad \text{......(36 c).}$$

The above types of solution hold for the special condition

$$\rho + \sigma - a = K \qquad \text{......(37),}$$

this being the condition for equal roots in (9).

When $\rho + \sigma - a$ is less than K, μ and ν become complex. This state is not a desirable one in practical applications, but it is of interest to note the chief properties of the motion when this is so. ν is now the conjugate of μ, so that in (36) y is made up of a complex and its conjugate and is thus twice the real part of the first term of this equation. We may write the first term

$$\frac{1}{2}\frac{(\mu - \rho)\,Y}{(\mu - \nu)\,(\sqrt{\mu^2 - 1})}\,(e^{-z\xi}/z - ze^{-\xi/z}),$$

in which

$$z = \mu - \sqrt{\mu^2 - 1}.$$

Since z is complex, put $z = Pe^{j\chi}$, and then

$$e^{-z\xi}/z = \frac{1}{P}\,e^{-\xi P\cos\chi}\,e^{-j(P\xi\sin\chi + \chi)}.$$

This represents a damped negatively rotating vector of initial amplitude $1/P$, initial phase lag χ, having an attenuation $e^{-2\pi\cot\chi}$ per cycle and a period $2\pi/P\omega_0\sin\chi$. Similarly $ze^{-\xi/z}$ is a damped positively rotating vector of initial amplitude P, phase lag $\pi - \chi$, having attenuation $e^{-2\pi\cot\chi}$ per cycle and period $2\pi P/\omega_0\sin\chi$. The term outside the bracket simply alters the scale and absolute phase of these rotating vectors equally. Thus the actual motion is a combination of two simple damped oscillations of equal logarithmic decrements. The two component oscillations are exact copies of each other, the time and amplitude scales being altered in the same ratio (P^2) in passing from one oscillation to the other. The slower period oscillation is thus also the predominant oscillation.

The combination of these oscillations should, under favourable circumstances, produce the phenomenon of beats.

The complete equation may be given in the case when μ and ν are small. Under these circumstances $\sqrt{\mu^2 - 1} = j$ while $z \doteq -j$.

Then, with

$$\mu = \alpha + j\beta,$$

$$y \doteq \text{real part}\ \frac{\alpha - \rho + j\beta}{j\beta}\,Ye^{-(\alpha - j\beta)\xi}\cos\xi$$

$$= Ye^{-\alpha\xi}\cos\xi\left(\cos\beta\xi - \frac{\alpha - \rho}{\beta}\sin\beta\xi\right), \qquad \text{......(38).}$$

Since β is small compared with unity, the term of period $2\pi/\beta\omega_0$ may be regarded as a slow modulation of a damped wave $Ye^{-\alpha\xi}\cos\xi$, so that the variation in amplitude of the oscillation $\cos\xi$ is

$$Ye^{-\alpha\xi}\left(\cos\beta\xi - \frac{\alpha-\rho}{\beta}\sin\beta\xi\right),$$

which is itself a damped oscillation representing the beats in the quicker oscillation.

9. *Illustrative Examples.* In illustration of the theory we take the case of a fibre of phosphor bronze of diameter 15μ and length 5 cm. tuned to a frequency of 400 cycles per second. A string of this type has a resistance of approximately 50 ohms and the value of β/α is about 100 sec.$^{-1}$, and with the usual flux density in the air gap the value of fR_c is about 4000 ohms per sec. The use of those values in (15) shows that $A^2/\alpha r$ is equal to 1000. Then by (12) we find that the correct time constant to employ in the tuned shunt is $R/L = 1100$. In order to make the motion critically dead beat (13) tells us that the inductance should be about 10 millihenries. The values of R and C follow immediately as 11 ohms and 16 μfd. If the inductance is greater than 10 millihenries and the same value of R/L employed, the free motion is oscillatory, while if we use a smaller inductance the free motion is over dead beat.

If we wish to reduce the back electromotive force of the combination to zero, (16) shows that we must use an inductance of 50 millihenries, a capacity of 3·2 μfd. and a resistance of 55 ohms. The free motion is in this case oscillatory.

If we depart from the condition $R/L = 1100$ both free motions are present. The following table has been calculated for various values of R, L being fixed at 10 millihenries and C at 16 μfd.

R	μ	ν	Initial ratio of two motions
1	0·296	0·744	0·381
2	0·285	0·775	0·333
4	0·266	0·834	0·246
6	0·250	0·890	0·169
8	0·237	0·943	0·098
10	0·225	0·995	0·032
11	0·220	1·020	0·000
12	0·215	1·045	− 0·031
15	0·202	1·118	− 0·120
20	0·175	1·245	− 0·266

The motion which is suppressed at 11 ohms is the oscillatory motion, the damping of which is such that the deflection is approximately halved per half cycle. This motion is due mainly to the mechanical constants. The unsuppressed motion is practically critically dead beat and is due mainly to the electrical constants.

We may note here that the neglect of the back electromotive force of the string led Irwin to the conditions

$$\frac{R}{L} = \frac{\beta}{\alpha}, \qquad \frac{R+r}{L} = 2\omega_0$$

instead of (12) and (13).

These conditions give for the present example

$$L = 10 \text{ millihenries}, \qquad R = 1 \text{ ohm}, \qquad C = 16\,\mu\text{fd}.$$

This corresponds to the first case of the table which shows that instead of the unwanted oscillation being suppressed, its initial amplitude is 0·381 of that of the unsuppressed motion. The full theoretical curves of motion for the cases $R = 1$, 11 and 20 ohms are shown in Figs. 1, 2 and 3 respectively. In illustration of the case where the values of μ and ν are complex we may take the same string with a shunt of 100 millihenries, 10 ohms and 1·6 μfd.

In this case, $\rho = 0{\cdot}02$, $\sigma = 0{\cdot}1$, $a = 0{\cdot}02$, $k^2 = 0{\cdot}08$. The quadratic (9) becomes

$$X^2 - 0{\cdot}14\,X + 0{\cdot}0224 = 0,$$

the roots of which are $$X = 0{\cdot}07 \pm 0{\cdot}132j.$$

Hence the envelope of the oscillations of 400 frequency is

$$y = Ye^{-175t}\,(\cos 330t - 0{\cdot}38 \sin 330t).$$

The curve of motion is shown in Fig. 4.

Einthoven Galvanometer with Resonant Shunt.
Types of Motion at "Break".
Galvanometer has resistance r, critical resistance Rc, open circuit log dec. δ period T. Shunt has inductance L, capacity C, resistance R

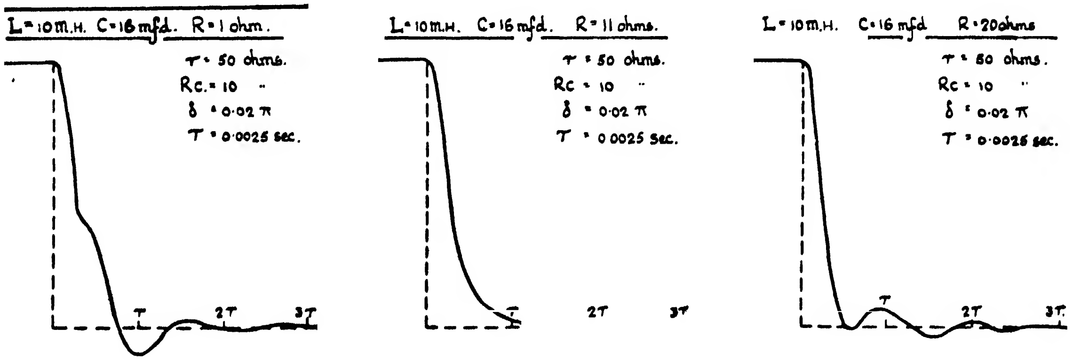


Fig. 1. Fig. 2. Fig. 3.

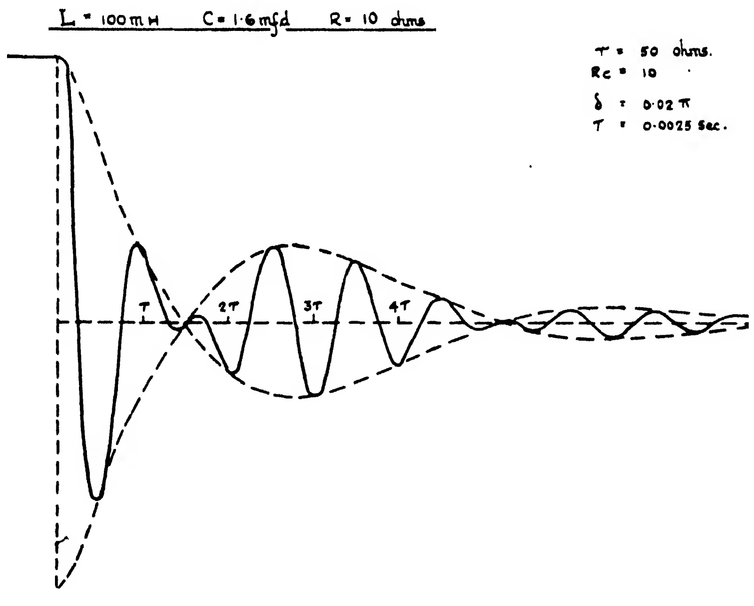


Fig. 4.

10. *Experimental Confirmation.* The photographic records reproduced in Figs. 5, 6 and 7 show how nearly the theory is fulfilled in practice. The instrumental constants used in the examples of Section 9 were closely approximated to in the galvanometer employed. In the records of Fig. 5 the string was tuned to a frequency of 400 cycles per second. (*a*) shows the free motion at break with no shunt.

In records (*b*), (*c*) and (*d*) a tuned shunt was employed having an inductance of 10 millihenries and a capacity of 16 μfd., the resistances being 3, 11 and 20 ohms respectively. Thus the records (*c*) and (*d*) should correspond to the theoretical curves shown in Figs. 2 and 3, while record (*b*) should be intermediate between the curve of Fig. 1 and that of Fig. 2. It is seen that the records follow the theoretical curves fairly faithfully, but there is superposed on the fundamental motion a pronounced third harmonic. Assuming this to be due to the third string harmonic a second shunt tuned to 1200 frequency should be able to damp it out. Accordingly records (*b*′), (*c*′) and (*d*′) were taken with a second shunt having an inductance of 10 mh., a capacity of 1·6 μfd. and a resistance of 3 ohms in parallel with the combination. It is seen that the third harmonic has disappeared and that the curves are now very faithful copies of the theoretical curves.

Records (*e*) and (*e*′) are for the case $L = 100$ mh., $C = 1{\cdot}6$ μfd., $R = 10$ ohms. In record (*e*) there is no third harmonic elimination, and in record (*e*′) the third harmonic has been eliminated by the above method. The record (*e*′) should correspond with Fig. 4. The beats are distinct, but there is some difference in the shape of the theoretical and experimental curves at the first null point. Upon repeating this case some days later, with apparently the same experimental conditions, the records of Fig. 6 were obtained.

Record (6*a*′) is a very good approximation to the curve of Fig. 4.

In the records of Fig. 7 the string was tuned to a frequency of 1500 cycles per second, and in records (*b*), (*c*) and (*d*) a shunt having an inductance of 2·35 mh. and a capacity of 4·9 μfd. was employed. The resistances were 0·4, 2·7 and 10 ohms respectively. Record (*a*) shows the open circuit motion. No attempt was made in this case to remove the third harmonic.

The constants used in obtaining record (*c*) are those which according to theory should give critical damping. The record shows that this condition has been brought about.

The authors desire to express their indebtedness to the Admiralty for permission to publish this paper.

A WIDE ANGLE ILLUMINATOR. By C. F. SMITH,

Designing Department: ADAM HILGER, Ltd.

[*MS. received*, 29*th May*, 1926.]

A SCALE of wave-lengths is of much assistance to those engaged in spectrographic research, since it provides a number of reference points for locating isolated lines or groups of lines in the spectrum. The scale is usually photographed on glass and in its simplest form consists of a transparency which may be laid on a spectrogram. When, by means of a known line, the scale has been accurately positioned the identity of the lines are determined. A more convenient method is that in which the wave-length scale is mounted inside the spectrograph in such a manner as to be brought at will in contact with the photographic plate. With suitable means of illumination a contact print of the wave-length scale can

thus be obtained on the same plate as, and in juxtaposition to, the photograph of the spectrum. In the quartz spectrographs manufactured by Adam Hilger, Ltd., the scale is mounted on the dark slide holder, and may be swung nearly into contact with the plate when desired. The illumination has been obtained hitherto by the lighting of a small pea lamp shown at *L* in Fig. 1, and although this has proved fairly satisfactory there are some practical objections which make it necessary to find an optical substitute. It is difficult to find standard lamps with a sufficiently small filament to provide a sharp shadow image through the scale, and having at the same time the advantages of standardised filament position and extended life. The light reflected from the back of the bulb also tends to increase the size of the luminous source and if one attempts to limit this by using a small aperture it is not easy to obtain the required wide angle of illumination, amounting to 90°. Further, the pea lamp is always of small voltage and usually requires a dry battery or accumulator, the objections to which are well known.

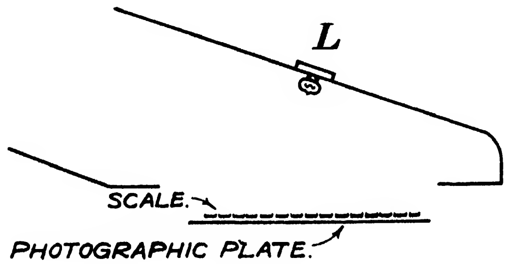


Fig. 1

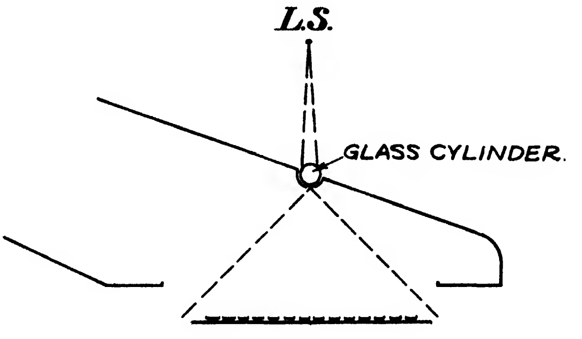


Fig. 2

Fig. 2 shows the arrangement suggested by the writer, in which a glass cylinder of small diameter is placed in the position hitherto occupied by the pea lamp. A small diaphragm 0·74 mm. in diameter is placed on the cylinder on the side nearest the scale and this serves to eliminate the glow due to internal reflections. The light source may be an ordinary 40 w. electric lamp placed about 4 inches from the illuminator, the exposure then being 20 seconds compared with 3 seconds with the pea lamp. Since it is possible to obtain a maximum angle of incidence of 180° the refracted light may cover nearly 200°, all of which

Fig. 3. Taken on Hilger Quartz Spectrograph with Wave-length Scale

proceeds from the small diaphragm. It may be said at once that this attachment has proved satisfactory, and an example of a spectrum, together with a wave-length scale illuminated by the above means, is shown in Fig. 3.

The expressions for angle of incidence, deviation, and aperture are simple but may be of interest.

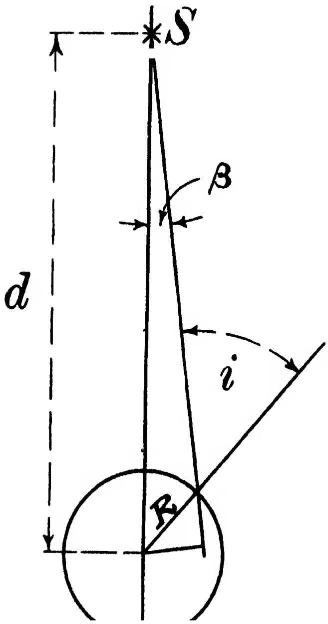


Fig. 4

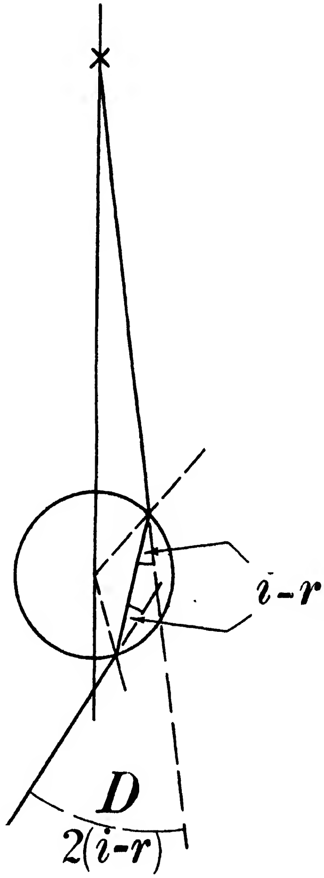


Fig. 5

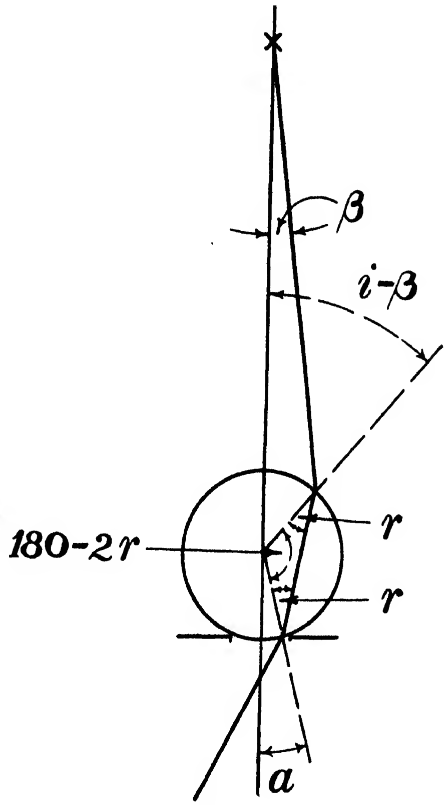


Fig. 6

Referring to Fig. 4:

d = distance from a point S on the luminous source to axis of cylinder.

R = radius of cylinder.

β = angle between the incident ray and the line joining S and the centre of the cylinder.

μ = index of refraction.

i = angle of incidence.

$$\frac{\sin i}{\sin \beta} = \frac{d}{R}.$$

$$\sin i = \frac{d \sin \beta}{R},$$

from which

$$\sin r \text{ (angle of refraction)} = \frac{d \sin \beta}{\mu R}.$$

Referring to Fig. 5:

D = angle of deviation

$= 2(i - r)$.

The formula for diaphragm aperture is illustrated by Fig. 6:

$\alpha =$ the angle of the radius at the point of emergence, from which the size of diaphragm may be obtained.

$$\alpha = 180 - (i - \beta + 180 - 2r)$$
$$= \beta + 2r - i.$$

Since the required angle of illumination is 90°, the corresponding value of D is 46°, $\alpha = 10° \ 40'$ and the diaphragm aperture is 0·74 mm. diameter.

These dimensions are based on: (1) distance of light source $= d = 102$ mm., (2) diameter of cylinder $= 2R = 4$ mm.

LABORATORY AND WORKSHOP NOTES

ELECTRICAL TEST ROOM EQUIPMENT. By C. V. DRYSDALE, D.Sc.

THE letter by Mr Kelly and the comments by Dr Russell which appear in this issue revive a subject of very great importance to the instrument manufacturer and those who are concerned in calibrating or checking indicating instruments or supply meters, and one on which comparatively little has been written. Modern requirements call for ammeters, voltmeters, wattmeters, supply meters, and instrument transformers capable of measuring from a few milliamperes to thousands of amperes, and from a few volts to a hundred kilovolts; and the standardizing instruments and supply and regulating devices usually involve a most elaborate and costly equipment.

It has long appeared to the writer that there is great need for simplification and standardisation of calibrating equipment so as to cover the field in the most simple and least costly manner; and the following suggestions may be of interest, although the writer does not pretend to have had experience with the heavy currents and high voltages of modern practice.

The cardinal principles which should apparently be borne in mind in a calibrating equipment are as follows:

1. The standardizing instruments should be as universal and few in number as possible, and be fixed in position, so as to avoid risk of derangement, and need the minimum amount of checking.
2. The supply and regulating arrangements should also be made to cover the whole range required with the minimum change of connexions.
3. Convenient arrangements should be made for mounting the instruments to be tested, and connecting them with the maximum of convenience and minimum of danger to the observer, and precautions should be taken against stray fields or leakage.

In dealing with A.C. and polyphase measurements several years ago the writer was impressed with the limited range of A.C. instruments owing to their square law, and accordingly introduced a modified form of Ayrton and Perry series parallel commutator into his standard single phase and polyphase wattmeters, both for the purpose of extending their range and of reducing eddy current errors. But a little further consideration showed that this principle was not only desirable for wattmeters and ammeters, but for the supply and regulating devices as well, and that the rational course would be to make the whole testing circuit of a number of similar circuits controlled by a single series-parallel commutator.

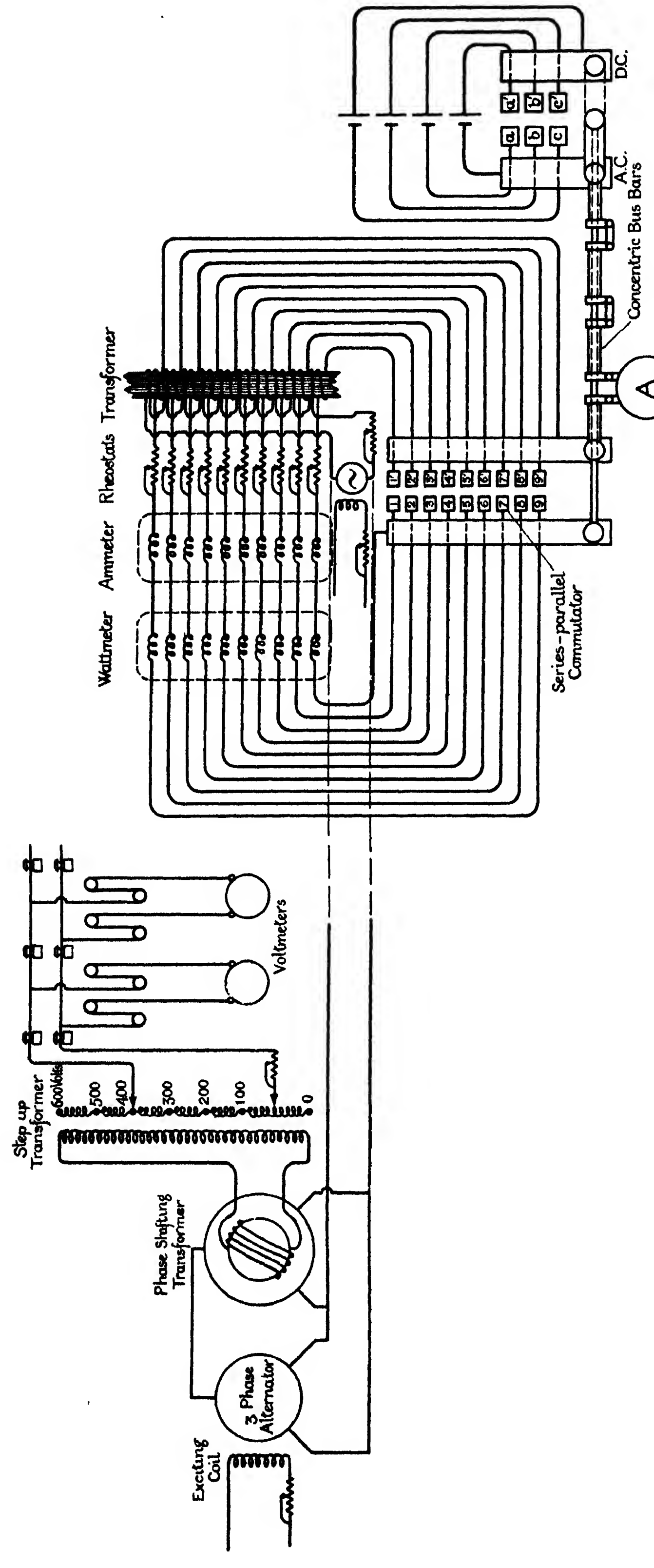


Fig. 1. Scheme of Connexions for D.C. or Single-Phase Ammeter, Voltmeter, Wattmeter, or Supply Meter Testing

Fig. 1 gives a diagram of connexions for D.C. and single-phase ammeter, voltmeter, wattmeter and supply meter testing, in which the current circuit is made up of ten similar elements each containing an ammeter and wattmeter coil, a rheostat and a secondary coil of a transformer giving about ·5 volt. These elements are connected to the commutator which enables them to be connected either wholly in series or in parallel, or in the combination of 5 series 2 parallel, or 2 series 5 parallel, so that the current ranges are in the ratio 1, 2, 5 and 10. This arrangement has many advantages, as a change in the commutator effects the changes in all the devices simultaneously and harmoniously, the supply voltage and capacity of the rheostats being exactly suited to the range in each case. If the sliders of the rheostats are mechanically coupled together and moved by a single handle the percentage change in the current for a given movement and the heating will be the same for every range. The standard instruments and leads are fixed in position so that there is no mechanical disturbance or alteration of magnetic fields from the leads and a check at one range is sufficient.

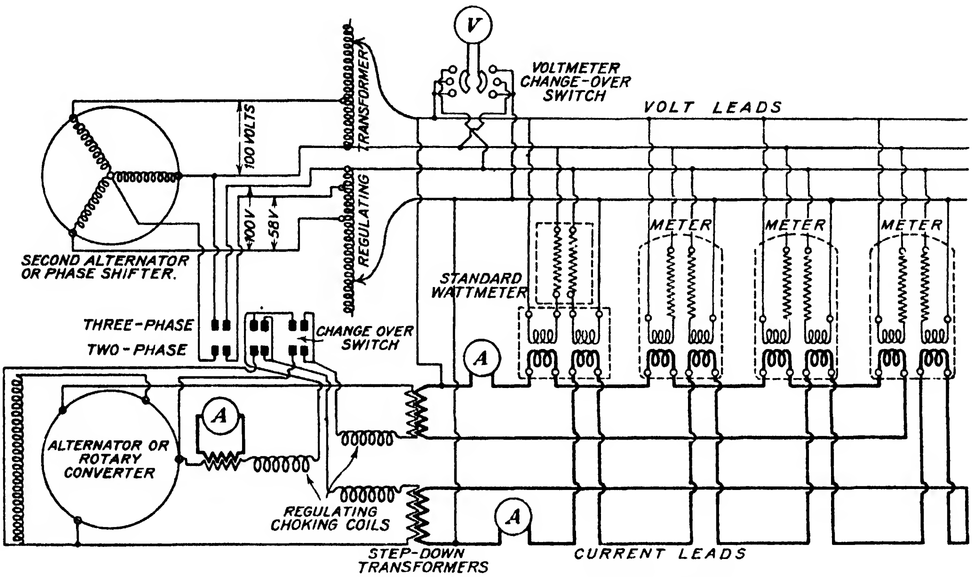
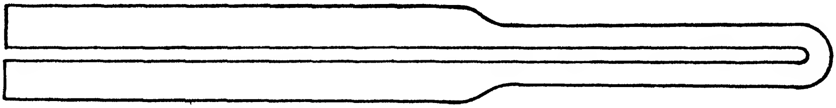


Fig. 2. Connexions for Single-, Two-, or Three-Phase Testing

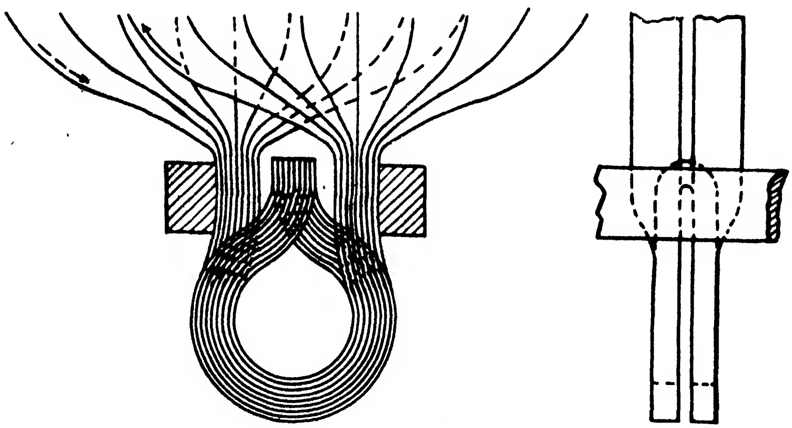
If the instruments have a useful range of 10 to 1, this gives a hundred fold range for the combination, and two such sets, one from 0·1 to 10 amperes and the other from 10 to 1000 amperes will cover the bulk of calibrating work. For the higher current set it is doubtful if anything is better for the rheostat than a set of ten pairs of mercury troughs each about 1 metre long and 1 cm. wide and tilted so that the depth is about 1 cm. at one end and 2 or 3 mm. at the other end. The resistance of the mercury is about 100 microhms per cm.[3] so that 20 metres of 1 sq. cm. section would have a resistance of 0·2 ohm or about ·5 ohm when tilted. This range is quite sufficient in combination with the change of P.D. of the cells or transformer, and the deeper part of the trough will easily carry 100 amperes in series or 1000 amperes with the ten pairs in parallel. The slides connecting adjacent troughs may be fixed on a single bar which traverses along them. True the arrangement requires about 50 lbs. of mercury which is expensive and should be covered over to avoid contamination, but the remainder of the construction is inexpensive, and no other type of heavy current resistance gives such uniform and constant gradation. Care must however be taken to keep up the depth of mercury, as if the current density is too high, the mercury column will break up and arc owing to the "pinch" phenomenon. As an alternative ten

carbon rheostats each capable of carrying 100 amperes may be employed, but these are less easily coupled mechanically and usually give some trouble owing to packing of the plates, so that it is difficult to secure approximate equality of the currents in the several circuits.

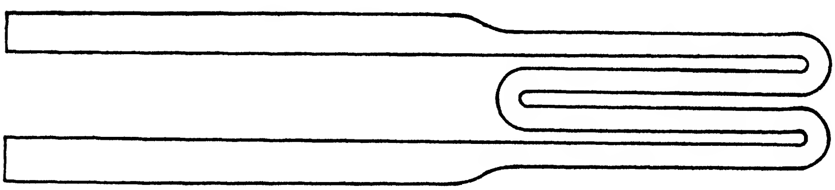
Where a number of instruments are to be calibrated in series and there is a risk of magnetic disturbance from long heavy current leads it is well to employ "bus bars" on the calibrating bench made of two concentric copper tubes, the outer one being cut at intervals and provided with terminals which can be connected by short straight leads to the instruments or be bridged across by a copper strap.



FORM OF STRIP FOR 2–20 TURN COIL



TWO TURN COIL SUITABLE FOR SOFT IRON AMMETER



FORM OF STRIP FOR 4–40 TURN COIL.

Fig. 3. Strip Windings

For direct current testing, cells must of course be used, but as these are generally of 2 volts each, ten of them in series would give too high a voltage, and 4 cells with a series parallel commutator are sufficient. A single change over switch or link is all that is necessary to change from A.C. to D.C. testing, as there is no objection to the D.C. passing through the transformer coils.

The P.D. side of the matter presents fewer difficulties except in the case of very high voltages, and needs comparatively little consideration. The series parallel arrangement is not of much use here, as the range of most electromagnetic voltmeters and wattmeters is extended simply by series resistances or equivalent devices, so that the current is not very different for different ranges of P.D. The most satisfactory method of regulating the

voltage is to have a number of transformers with primaries in parallel and secondaries which can be added in series by a dial switch as required, one of these transformers having tappings at each volt or ten volts. The P.D. can then be set immediately to approximately the required value by the dial switches and adjusted to the exact value by a series rheostat. For D.C. calibration however, the series parallel commutator is an advantage, as it enables a number of banks of cells to be put in series for working and in parallel for charging.

For wattmeters, supply meters, and phase meters, phase variation is also necessary and this is often effected by having two coupled alternators, one of which is connected to the primary of the transformer supplying the current, while the other, which has a rotatable body, is connected to the primary of the P.D. transformer. The writer however prefers to

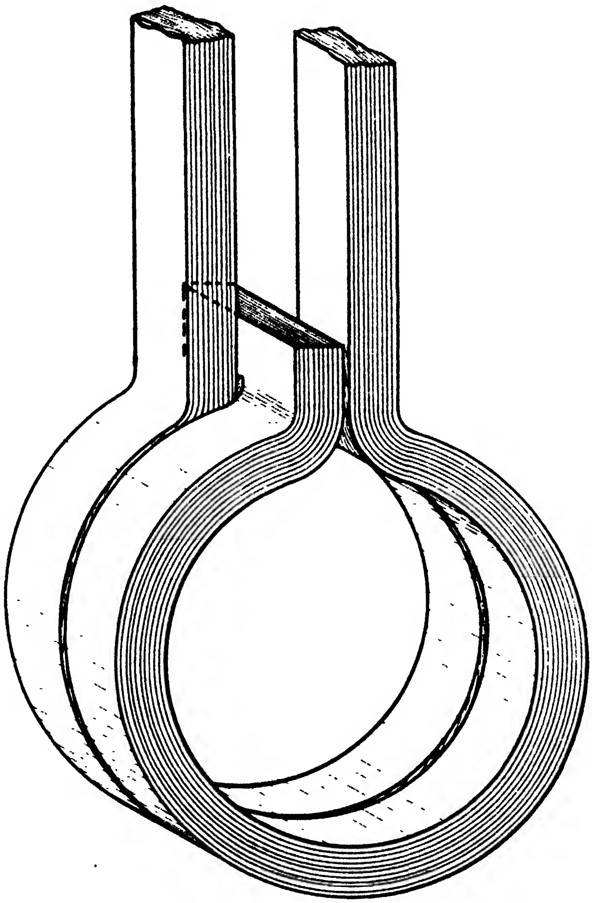


Fig. 4. Perspective View of Strip Wound Coil

use a single two- or three-phase alternator with a phase shifting transformer having its rotatable secondary connected to the P.D. transformer. This has the advantage of having the phase control directly at the calibration bench. The secondary of the phase shifting transformer is connected to the step-up transformers with dial switches from which two leads on porcelain insulators are carried well out of reach above the calibration bench. Hanging leads are tapped from these and provided with counterweight fittings so that they can be reached up for when connecting up an instrument but fly up out of harm's way when released. Fig. 2 taken from *Electrical Measuring Instruments* by Mr A. C. Jolley and the writer shows a complete diagram of connexions for both single-phase, two-phase, and three-phase calibration or checking, and will be fairly self evident. The only point to

which attention may be drawn is the provision of what are called "equalizing leads" between the P.D. and current circuits, which ensure that the potentials in each element of the instrument under test are the same as under working conditions on real instead of an artificial load.

A word should perhaps be added as to the method of winding the standard instrument coils so as to provide most easily for the series parallel connexion. Figs. 3 and 4 show a form of strip winding devised by the author, but which seems to have been previously put forward by Messrs Siemens Bros. It can easily be used for an ammeter or wattmeter, and takes little more space than an unstranded coil. The strips are cut of U shape and insulated with a single layer of varnished silk after which ten of them are laid together and the bundle is wound in opposite directions round a rod so as to form a double turn coil each of ten layers. It will be seen that the outer strip in one turn becomes the outer in the other turn and vice-versa so that all the circuits have approximately the same total area and magnetic effect, and the current tends to divide equally between them when in parallel, even at fairly high frequencies. The double twist also brings the leads out in the most convenient order for connexion to the series parallel commutator, and the strips of the ammeter can be individually connected to those of the wattmeter etc. as diagrammatically shown in Fig. 1. A model soft iron ammeter constructed by the writer with this type of coil gave good readings from 1 to 150 amperes D.C. or A.C.

Although these schemes were got out some years ago and have only been briefly described, it is hoped they may be of some interest and assistance to those who are contemplating the installation of a calibrating or meter testing outfit.

FLATTENING THIN METAL SHEETS. By E. H. BANNER, M.Sc., A.Inst.P.

[*MS. received, 27th September*, 1926.]

Some time ago a number of electrostatic voltmeter vanes were required by the writer to be flattened. The metal was duralumin, of ·005 inch thickness, the vanes were cut to size, actually about $4 \times 2\frac{1}{2}$ inches, drilled and flattened. After drilling the plates were badly warped, and were of no use for the purpose. The following process was found to be efficacious, the vanes being quite true when finished.

Two pieces of cast iron, of size larger than the vanes and about half an inch thick, were machined on one face, and placed on a gas-ring with a vane between the machined surfaces.

The temperature of the whole was raised to about 350° C., and maintained for ten minutes. The gas was then turned off and the whole left to cool slowly. On becoming quite cold the top block was removed and the vane taken off and found to be quite true.

A cupro-nickel vane was tried in a similar way but was not successful.

CHECKING THREAD GAUGES. By B. BROWN, B.Sc.(Eng.)

[*MS. received, 28th August*, 1926.]

The screw thread is possibly the most important device in the whole of engineering. Although the majority of screws and nuts are used only as fasteners and thus are required to be moved at the most only a few times, it is essential that their size be standardized. To this end a variety of gauges are employed. It is the aim of all those occupied in producing mechanical parts to turn out their product as accurate as possible consistent with proper functioning. This follows from the consideration of economical manufacture. So that the greatest amount of latitude may be given to the final product the gauges used must in themselves possess the highest possible accuracy as commerically obtainable. A screw gauge is one of the most difficult jobs to produce and so a few words on the checking of such may prove of value even to those not directly engaged upon their manufacture.

Roughly speaking a screw possesses five elements which are:

(1) Outside or full diameter.
(2) Core or root diameter.
(3) Effective or pitch diameter.
(4) Pitch, sometimes termed the lead.
(5) Form including the radii.

For the moment we will confine our attention to the plug portion of the thread. Item number (1) is the easiest to check: the operation may be performed with a good micrometer calibrated to read in ten thousandths, though it is preferable to employ Swedish slip gauges or their British equivalent.

The core diameter, (2) is measured by use of either of the above mentioned measuring devices coupled with an anvil which reaches to the bottom of the thread. Here it may be mentioned that very often these anvils, which are in the form of a wedge having an included angle less than that of the thread, have too large a radius at the bottom and so fail with the smaller variety of screws.

The effective diameter, (3) is the most difficult diameter to measure. Although there are special micrometers on the market which are supposed to give this dimension directly their use is not to be recommended for gauge work. The standard method for checking the effective diameter is by the three wire system. In it a measurement is taken over the tops of three wires of known diameters which rest in the vee of the thread. The size of the wires must be such that the points of contact with the flanks of the threads are approximately midway down the total thread depth. From the figures thus obtained the effective diameter can be calculated in a simple manner. Generally speaking the formulae used ignore the helix angle of the screw. The error in this way introduced is not more than one hundred thousandth so long as the pitch of the screw is not excessive when compared with the diameter.

The three diameters discussed above may be taken with the ordinary micrometer. A much better way is to use one of the "floating" micrometers where the plug is supported between centres and the micrometer automatically takes up a suitable position. In such instruments there is also a device which enables all readings to be taken under the same conditions of pressure; this is a very important point where wires are used between the threads since the wedging action is then considerable. It is in the measurement of the effective diameter that the benefit of this type of micrometer is felt most. If an ordinary hand micrometer is used it will be found to be a very tricky business to control three wires, the micrometer screw and the gauge in question with one pair of hands.

In the making of commercial gauges the pitch, (4) is very often not checked. The omission is not so serious as may appear at first sight. If the lathe upon which the gauge has been chased has a good lead screw no trouble should be experienced with the pitch of the gauge. There are several machines upon the market which will show up pitch error but the price is somewhat high. A method exists whereby any pitch error may be found by measurements of the effective diameter but it is not in general use.

The form of the thread is the element which receives very little attention from ordinary gauge makers. The only way in which it may be checked is by use of some optical magnifying device notably the projector. These instruments are fairly expensive but a handier tool for the precision worker would be hard to find. If desired the projector may be used for taking actual measurements of thread depth and so gives an additional check upon the core and effective diameters. It is customary to draw out charts showing a few threads to an enlarged scale—that at which the projector is used. These charts are used for direct comparison with the shadow profile thrown upon the screen.

Ring gauges are checked in a similar manner to the plugs but the process is more difficult.

Where the diameter is small it is almost impossible to get good readings. Instead of three wires being used for the determination of the effective diameter three standard balls are inserted in the thread grooves and the distance apart taken with the inside jaws of a micrometer or a combination of slip gauges. The core diameter is even more difficult to measure since the anvils must have the edge cut to a radius smaller than that of the screw. Here we are speaking of the large side radius and not the small one which is in reality the knife edge.

The form is found by means of the projector through the medium of a cast often made from a mixture of sulphur and graphite.

It should be understood definitely that the foregoing remarks apply only to workshop gauges and not to the master check which is of course beyond the scope of the ordinary gauge maker.

RESONANT SHUNTS

THE paper by Messrs Butterworth, Wood, and Lakey, which appears in this issue, is a very important contribution to the technique of string galvanometers and oscillographs. To Mr J. T. Irwin the credit is due for the first proposal of a resonant shunt for the damping of such instruments, but the authors have now evolved a more complete theory and ascertained the simple conditions for obtaining the best effect—viz. that the free electrical oscillation in the shunt when short-circuited should be an exact copy of the free mechanical oscillation of the string when short-circuited; and that for critical damping of a practically undamped string, the reactance of the shunt at the resonant frequency of the string should be half the resistance of the string. It is fairly easy to calculate the resistance inductance and capacity in the shunt required to satisfy these conditions, and thus to obtain the best results without tedious experimenting.

CORRESPONDENCE

TESTING AND CALIBRATION OF METERS

I SHALL be much obliged for your advice on the following matter:

We are equipping a test room for the testing and calibration of electrical instruments, meters, etc., such as are in general use on a large railway system.

For providing current for the testing of direct current meters we have a 4-cell lead storage battery which, with the cells in parallel, will give currents up to 3000 amp. at 2 volts.

The table attached herewith shows the range of resistances required for various test currents which necessarily have to cover a wide range because, in practice, we generally have to test individual instruments and cannot connect up several similar instruments in series for a simultaneous test as in factory practice.

		Volts			Resistance scheme	
Test amps.		Supply volts	Drop in leads (min.)	Drop in shunts and instruments	Volts to be absorbed	Ohmic range
5		2·0	0·002	0·95	1·048	0·21
50	Min.	,,	0·02	0·2	0·83	0·0166
	Max.	,,	,,	1·15	1·78	0·0356
100	Min.	,,	0·04	0·2	0·81	0·0081
	Max.	,,	,,	1·15	1·76	0·0176
300	Min.	,,	0·12	0·2	0·73	0·0024
	Max.	,,	,,	1·15	1·68	0·0056
500	Min.	,,	0·2	0·2	0·65	0·0013
	Max.	,,	,,	1·15	1·60	0·0032
1000	Min.	,,	0·4	0·2	0·45	0·00045
	Max.	,,	,,	1·15	1·40	0·0014
2000	Min.	,,	0·8	0·2	0·05	0·000025
	Max.	,,	,,	1·15	1·00	0·0005
3000	Min.	,,	1·2	0·2	0·40	0·00013
	Max.	,,	,,	0·4	0·60	0·0002

Our problem is to find the best form of readily variable resistance to secure these results and to carry these currents. We have tried a liquid resistance with iron plates immersible to various depths in salt and in potassium hydrate solutions but this is cumbrous and "messy" and the result is not satisfactory.

I shall be very much obliged for any advice you can give me on this subject.

FERROCARRIL DE BUENOS AIRES AL PACIFICO
BUENOS AIRES,
26 *July*, 1926

A. C. KELLY,
Chief Electrical Engineer.

WE sympathize with Mr Kelly. Liquid resistances are not a sound engineering proposition.

For testing meters up to 3000 amperes we use ten switches in parallel each making a circuit through a resistance. The smallest resistance is of iron wire about $\frac{1}{8}$th of an inch in diameter and it takes about 30 amperes at 12 volts and 5 amperes at 2 volts.

The largest consists of several strips, about $3'' \times \frac{1}{16}''$ in cross section, of eureka and it takes about 700 amperes at 2 volts.

There is also an adjustable-pressure carbon resistance which can take up to 30 amperes. We have used practically the same arrangement for many years and it has never given any trouble.

ALEXANDER RUSSELL.

[This subject is referred to in Laboratory and Workshop Notes. Ed. Journal.]

PUBLICATIONS RECEIVED

Handbuch der Physik. Edited by H. GEIGER and K. SCHEEL. Band IX, Theorien der Wärme. Edited by F. HENNING. Pp. 616. Price 49.20 Reichsmark. Band I, Geschichte der Physik. Vorlesungstechnik. Edited by KARL SCHEEL. Pp. 404. Price 33.60 Reichsmark. Band II, Elementare Einheiten und ihre Messung. Edited by KARL SCHEEL. Pp. 552. Price 42 Reichsmark. Julius Springer. Berlin.

Physico-Chemical Methods. By J. REILLY, M.A., D.Sc., W. N. RAE, M.A., F.I.C. and T. S. WHEELER, Ph.D., B.Sc. Pp. 720. Methuen and Co., London. Price 30*s.* net.

Surface Equilibria of Biological and Organic Colloids. By P. LECOMTE DU NOUY, D.Sc., with introductions by Dr A. CARREL and Prof. R. A. MILLIKAN. Pp. 212. The Chemical Catalog Company Inc., 19 East 24th St., New York, U.S.A.

Tungsten. A Treatise on its Metallurgy, Properties and Applications. By C. J. SMITHELLS, M.C., D.Sc. Pp. 167. Chapman and Hall, Ltd. Price 21*s.* net.

The Editor would be obliged if all communications are addressed to him in future at *The National Physical Laboratory, Teddington, Middlesex.*

TABULAR INFORMATION ON SCIENTIFIC INSTRUMENTS

The subjoined table gives particulars of various forms of laboratory type soft iron ammeters and voltmeters, as furnished by their respective manufacturers. Separate copies of this table can be obtained on application to Mr G. W. Marlow, B.Sc., Secretary, The Institute of Physics, 90, Great Russell Street, London, W.C. 1.

XIII. SOFT IRON LABORATORY AMMETERS AND VOLTMETERS

List No.	Description (attraction, repulsion, etc.)	Dimensions: Pointer length mm.	Dimensions: Scale length mm.	Dimensions: External mm.	Range to amps or volts	scale dimensions	Resistance ohms	Inductance millihenrys	Accuracy % of max. reading	Periodic time sec.	Damping sec.	Remarks	LIST PRICE £ s. d.
Maker:—CROMPTON & CO., LTD., CHELMSFORD, ESSEX.													
	"L.K.D." portable ammeter. Repulsion	93	190	203 × 213 × 76	As required	To suit range	—	—	1st grade	1½	3	Dimensions are for case only	According to range required
	"L.K.D." portable voltmeter. Repulsion	93	190	,,	60–600, 30–300, 15–150, or as required	Scale 0–150 75 parts	12,000 6,000 3,000	—	,,	,,	,,	—	,,
	M.I. testing set. Attraction	88·5	115	324 × 220 × 137	0·5–5 a.	50	·03	—	1st grade on A.C.	,,	,,	External shunt for ammeter	,,
					15–150 v.	75	25 ohms per v.	—				Extra resistance for volt ranges	
Maker:—EDISON SWAN ELECTRICAL CO., PONDERS END, MIDDLESEX.													
Z 1931/48	M.I. portable wood case	85	95	195 × 215 × 95	15–600 a. 10–800 v.	40	30 ohms per v.	—	2	—	3	—	Varies with range of inst.
Z 1991/96	M.I. portable testing set	90	130	270 × 250 × 160	5–200 a. 30–600 v.	40	30 ohms per v.	—	2	—	3	—	17 6 0 to 19 3 2
Maker: ELLIOTT BROS. (LONDON), LTD., CENTURY WORKS, LEWISHAM, S.E. 13.													
Type O	Milliammeter. (Attract.)	Knife-edge 3¼ in. length	4¾ in.	8 × 7½ × 3½ in.	50 ma. and up.	100	160	20	½	2	80 %	Shielded	9 0 0
,,	Ammeter, 1 to 500 a.	,,	,,	,,	1·0	,,	0·4	0·06	,,	,,	,,	,,	9 0 0
	,,	,,	,,	,,	5 a. and up.	,,	0·02	0·0022	,,	,,	,,	,,	9 0 0
,,	Voltmeter. (Attract.)	,,	,,	,,	5 v.	,,	32	0·05	,,	,,	,,	,,	9 0 0
	,,	,,	,,	,,	100 v.	,,	620	62	,,	,,	,,	,,	9 0 0
Type SAO	Milliammeter. (Repulsion)	3¼	5¼	7 × 7 × 3½ in.	50	100	490	968	¼	1·5	95 %	Special shielding	10 0 0
	Ammeter, 1 to 300 a.	,,	,,	,,	5	,,	0·04	0·09	,,	,,	,,	,,	10 0 0
	Voltmeter from 30 v.	,,	,,	,,	100 v.	,,	1700	968	,,	,,	,,	,,	10 10 0
Maker:—EVERETT, EDGCUMBE AND CO., LTD., COLINDALE WORKS, HENDON, N.W. 9, AND 117, VICTORIA ST., S.W. 1.													
U.P.S.	Portable precision moving-iron voltmeter	95	120	220*, 180*, 150	Any range between 0–10 v. and 0–1000 v. (or more by means of volt. transformers)	100–150 according to range	According to range	According to range	As BESA sub-standard on A.C.	As BESA	Pneumatic	These voltmeters are supplied in single or multi-ranges as required	Varies according to range etc.
J.P.	Portable industrial moving-iron voltmeter for general work	73	150	Ditto*	Ditto	According to range	Ditto	Ditto	Ditto. 1st grade A.C. and D.C.	Ditto	Ditto	Ditto	
U.P.S.	Portable precision moving-iron ammeter	95	120	Ditto	Any range from 0–100 ma. to 0–510 a. (or more by means of current transformers)	100–150 according to range	Ditto	Ditto	Ditto, sub-standard on A.C.	Ditto	Ditto	These ammeters are supplied in single and multi-ranges	
J.P.	Portable industrial ammeter for general testing work	73	150	Ditto*	Any range	Ditto	Ditto	Ditto	Ditto 1st grade A.C. and D.C.	Ditto	Ditto	Ditto	

* Smaller sizes are available.

List No.	Description	Pointer length mm.	Scale length mm.	External mm.	Range to amps or volts	scale dimensions	Resistance ohms	Inductance millihenrys	Accuracy % of max. reading	Periodic time sec.	Damping sec.	Remarks	LIST PRICE £ s. d.
Maker:—MESSRS JOHNSON & PHILLIPS, LTD., CHARLTON, S.E. 7.													
110 B	Repulsion type voltmeter	75	132	204 dia. × 155 mm. deep	Blank	100	Bobbin 200 ohm appr.	1·5 henries approx. at full scale deflec.	± 2	·95 sec.	4·5 dyne cm. per unit angular deflec.	Spring controlled, air damped by rectangular vane in sector box	2 7 3
111 B	,,	,,	,,	,,	50	,,	,,	,,	,,	,,	,,	,,	2 6 0
112 B	,,	,,	,,	,,	80	,,	,,	,,	,,	,,	,,	,,	2 6 3
113 B	,,	,,	,,	,,	100	,,	,,	,,	,,	,,	,,	,,	2 6 8
114 B	,,	,,	,,	,,	120	,,	,,	,,	,,	,,	,,	,,	2 7 3
115 B	,,	,,	,,	,,	160	,,	,,	,,	,,	,,	,,	,,	2 8 10
116 B	,,	,,	,,	,,	200	,,	,,	,,	,,	,,	,,	,,	2 11 11
117 B	,,	,,	,,	,,	260	,,	,,	,,	,,	,,	,,	,,	2 12 3
118 B	,,	,,	,,	,,	300	,,	,,	,,	,,	,,	,,	,,	2 15 4
119 B	,,	,,	,,	,,	400	,,	,,	,,	,,	,,	,,	,,	3 0 5
120 B	,,	,,	,,	,,	500	,,	,,	,,	,,	,,	,,	,,	3 4 5
121 B	,,	,,	,,	,,	600	,,	,,	,,	,,	,,	,,	,,	3 6 5

List No.	Description (attraction, repulsion, etc.)	Dimensions: Pointer length mm.	Dimensions: Scale length mm.	Dimensions: External mm.	Range to amps or volts	No. of scale dimensions	Resistance ohms	Inductance millihenrys	Accuracy % of max. reading	Periodic time sec.	Damping sec.	Remarks	LIST PRICE £ s. d.
Maker:—MESSRS JOHNSON & PHILLIPS, LTD., CHARLTON, S.E. 7 (*continued*).													
97 B	Repulsion type ammeter	75	132	204 dia. · 155 mm. deep	Blank	100	Bobbin 200 ohm appr.	1·5 henries approx. at full scale deflec.	±3	·95 sec. undamped	4·5 dyne cm. per unit angular deflec.	Spring controlled, air damped by rectangular vane in sector box	2 2 0
98 B	,,	,,	,,	,,	30	,,	,,	,,	,,	,,	,,	,,	2 2 0
99 B	,,	,,	,,	,,	50	,,	,,	,,	,,	,,	,,	,,	2 4 2
100 B	,,	,,	,,	,,	60	,,	,,	,,	,,	,,	,,	,,	2 4 3
101 B	,,	,,	,,	,,	80	,,	,,	,,	,,	,,	,,	,,	2 4 4
102 B	,,	,,	,,	,,	100	,,	,,	,,	,,	,,	,,	,,	2 5 3
103 B	,,	,,	,,	,,	120	,,	,,	,,	,,	,,	,,	,,	2 6 0
104 B	,,	,,	,,	,,	150	,,	,,	,,	,,	,,	,,	,,	2 6 5
105 B	,,	,,	,,	,,	200	,,	,,	,,	,,	,,	,,	,,	2 8 5
106 B	,,	,,	,,	,,	250	,,	,,	,,	,,	,,	,,	,,	2 13 3
107 B	,,	,,	,,	,,	300	,,	,,	,,	,,	,,	,,	,,	2 18 3
108 B	,,	,,	,,	,,	400	,,	,,	,,	,,	,,	,,	,,	3 2 2
109 B	,,	,,	,,	,,	500	,,	,,	,,	,,	,,	,,	,,	3 9 6
Maker:—METROPOLITAN-VICKERS ELECTRICAL CO., LTD., TRAFFORD PARK, MANCHESTER.													
	Portable Type S moving iron. Voltmeter	90	145	8 · 7¼ · 3¼ in.	0/5 or 0/10	100	3·3 per volt full scale	—	B.E.S.A.	—	—	Any number of ranges up to 3	See Price Lists
	,,	,,	,,	,,	0/25 to 0/50	,,	5 per volt full scale	—	—	—	—	Self-contained	
	,,	,,	,,	,,	0/51 to 0/80	,,	10 per volt full scale	—	—	—	—	,,	
	,,	,,	,,	,,	0/100 to 0/800	,,	20 per volt full scale	—	—	—	—	,,	
	Ammeter	,,	,,	,,	0/0·5 to 0/300	,,		—	—	About 2·5 sec.	6	—	See Price Lists
	,,	,,	,,	,,	0/0·5–1–2	,,	—	—	—		—	3 range self-contained	
	,,	,,	,,	,,	0/1·25–2·5–5	,,	—	—	—	—	—	,,	
	,,	,,	,,	,,	0/2·5–5–10	,,	—	—	—	—	—	,,	
	,,	,,	,,	,,	0/5–10–20	,,	—	—	—	—	—	,,	
	,,	,,	,,	,,	0/10–100. Other ranges up to 1000 with shunts	—	—	—	—	—	—	2 range self-contained, with shunts for other ranges up to 1000 a.	
Maker:—NALDER BROS. & THOMPSON, LTD., 97 a, DALSTON LANE, DALSTON, LONDON, E. 8.													
	Substandard ammeter	4⅝ in.	Length of arc 5⅛ in. Angle of deflection 68°	Length 9½ in. Breadth 8¼ in. Depth 6¾ in.	·5–5 a.	90	·0256	Negligible	B.E.S.A. specification No. 89 for substandard instruments	Comes to rest in two seconds with one overswing	Air-damping	This instrument is made for small currents only, the commonest range being 5 amperes for use with precision type series transformers. We do not make moving iron substandard voltmeters. Where substandard voltmeters are required for A.C. the dynamometer type is employed	7 7 0
Maker:—PARK ROYAL ENGINEERING CO., LTD., CUMBERLAND AVENUE, PARK ROYAL, N.W. 10.													
P.A. 702	Portable M.I. ammeter. (Repulsion)	90	114	6½ × 6¼ × 3⅜ in.	0–500 ma.	80	—	—	1	2·5	Air vane in chamber	Particulars given are for instruments of B.S. substandard grade	4 10 4
P.A. 703	,,	,,	,,	,,	0–20 a.	80	—	—	,,	,,	,,	,,	4 10 4
P.A. 704	,,	,,	,,	,,	0–40 a.	120	—	—	,,	,,	,,	,,	4 13 4
P.A. 705	,,	,,	,,	,,	0–60 a.	100	—	—	,,	,,	,,	,,	4 18 2
P.A. 706	,,	,,	,,	,,	0–100 a.	80	—	—	,,	,,	,,	,,	5 3 8
P.A. 707	,,	,,	,,	,,	0–120 a.	100	—	—	,,	,,	,,	,,	5 6 4
P.A. 708	,,	,,	,,	,,	0–150 a.	120	—	—	,,	,,	,,	,,	5 8 10
P.A. 709	,,	,,	,,	,,	0–200 a.	80	—	—	,,	,,	,,	,,	5 13 2
P.A. 710	,,	,,	,,	,,	0–250 a.	100	—	—	,,	,,	,,	,,	5 15 0
P.A. 711	,,	,,	,,	,,	0–300 a.	120	—	—	,,	,,	,,	,,	5 15 10
P.V. 721	Portable M.I. voltmeter. (Repulsion)	,,	,,	,,	0–20 v.	80	120	—	1	3·0	,,	,,	4 13 4
P.V. 722	,,	,,	,,	,,	0–60 v.	100	540	—	,,	,,	,,	,,	4 13 4
P.V. 723	,,	,,	,,	,,	0–80 v.	120	720	—	,,	,,	,,	,,	4 15 6
P.V. 724	,,	,,	,,	,,	0–100 v.	80	1,200	—	,,	,,	,,	,,	4 18 6
P.V. 725	,,	,,	,,	,,	0–120 v.	100	1,440	—	,,	,,	,,	,,	5 1 2
P.V. 726	,,	,,	,,	,,	0–160 v.	120	1,920	—	,,	,,	,,	,,	5 3 8
P.V. 727	,,	,,	,,	,,	0–200 v.	80	4,000	—	,,	,,	,,	,,	5 6 4
P.V. 728	,,	,,	,,	,,	0–300 v.	120	6,000	—	,,	,,	,,	,,	5 16 8
P.V. 729	,,	,,	,,	,,	0–400 v.	120	8,000	—	,,	,,	,,	,,	6 4 6
P.V. 730	,,	,,	,,	,,	0–600 v.	100	12,000	—	,,	,,	,,	,,	6 12 0
P.V. 731	,,	,,	,,	,,	0–800 v.	120	16,000	—	,,	,,	,,	,,	7 0 0

List No.	Description (attraction, repulsion, etc.)	Dimensions: Pointer length mm.	Dimensions: Scale length mm.	Dimensions: External mm.	Range to amps or volts	No. of scale dimensions	Resistance ohms	Inductance millihenrys	Accuracy % of max. reading	Periodic time sec.	Damping sec.	Remarks	LIST PRICE
Maker:—THE RECORD ELECTRICAL Co., LTD., BROADHEATH, ALTRINCHAM, CHESHIRE.													£ s. d.
C 11	Change coil test set	93	140	13¼ × 11¼ × 5 in. Weight 11 lb.	See leaflet	75 approx.	See leaflet	—	See leaflet	2·6 sec.	Air 14 % overshoot	Ammeter	49 17 0 Subject
	,,	,,	,,	,,	,,	,,	,,	—	,,	3·0 sec.	14 % overshoot	Voltmeter	,,
C 3	Portable voltmeter	,,	152	7½ × 8 × 3¾ in. Weight 4 lb.	150 v.	130	20 per v.	—	1	2·6 sec.	14 %	—	6 9 7 Liberal discounts
Maker:—SALFORD ELECTRICAL INST. Co., PEEL WORKS, SILK ST., SALFORD, LANCS.													
	6 in. dial portable voltmeter, iron case, mirror inset	97·5	140	7 × 7 × 4 in.	1·0–15·0	140	60	—	1st grade	2 sec.	Air vane	Can be had in the following ranges: 1·5, 15, 150, 300 and 600. Also 2 or 3 range	From 4 13 9 according to range
	6 in. dial portable ammeters, iron case, mirror inset	,,	,,	,,	,,	,,	0·02	—	,,	,,	,,	Can be had in the following ranges: 1·5, 5, 15, 75, 150 and 300	From 4 10 9 according to range
Maker:—THE SIFAM ELECTRICAL INSTRUMENT Co., 95 QUEEN VICTORIA STREET, E.C. 4.													
R 14 Precision	Ironless—attraction between two coils: Ammeter	92	130	175 × 200 × 100	2·5–5 or 5–10	1	0·92 0·23 0·36 0·09	1·75 va.	·4	3	Air	Series, etc., parallel coupling	12 6 8
	Voltmeter	,,	,,	,,	75, 150, 300 v.	,,	20 ω per v.	—	,,	,,	,,	3 terminals	10 0 0 to 13 0 0
	Wattm. a. Resist. ω 2·5–5 ·28–·07 5–10 ·084–·021	,,	,,	,,	75–150 or 150–300 or 125–250	a. 2·5–5 or 5–10	1000 ω for 30 v.	On application, see resistance	,,	,,	,,	3 terminals, volts and series and parallel coupling	13 0 0 to 16 0 0
R 4	Iron stampings magnetic circuit: Ammeter	,,	,,	130 × 180 × 190	2·5–5 or 5–10	,,	0·6 0·15 0·2 0·05	3·75 5	·7	2	,,	Ironclad unaffected by external fields	12 0 0 to 15 0 0
	Voltmeter	,,	,,	,,	75, 150, 300	,,	23 ω per v.	—	,,	,,	,,	3 terminals	
	Wattm. a. Resist. a. 2·5–5 ·192–·048 5–10 ·068–·017	,,	,,	,,	75–150, 150–300, 125–250 v.	,,	40 ω per v.	On application, see resistance	,,	,,	,,	3 terminals, volts and series and parallel coupling	11 0 0 to 23 0 0
	Wattmeter 3-phase unbalanced load, same as above but	—	—	170 × 180 × 190	—	—	—	—	—	—	—	Id. on each circuit	
Maker:—THE STONEBRIDGE ELECTRICAL Co., LTD., VICTORIA ROAD, NORTH ACTON, W. 3.													
59001 to 59005	Repulsion, Type EAATv	42	7	120 × 115 × 90	Up to 250 v.	20–50	1000 ohms at 100 v.	—	1·5	—	Air	Oak case and leather carrying strap	2 5 0
59031 to 59040	Repulsion. Type EAATa	,,	,,	,,	Up to 200 a.	,,	—	—	,,	—	,,	,,	2 6 0
59010 to 59027	Repulsion. Type ECTv	92	15	220 × 200 × 180	5 to 800 v.	75–100	1000 ohms at 100 v.	—	1	—	,,	Oak case with hinged lid and carrying strap. 1 or 2 ranges	3 5 0 to 5 8 0
59041 to 59058	Repulsion. Type ECTa	,,	,,	,,	10–500 a.	,,	—	—	,,	—	,,	Oak case with hinged lid and leather carrying strap. 1, 2 or 3 ranges	3 3 0 to 5 10 0
Maker:—THE WESTON ELECTRICAL INSTRUMENT Co., LTD., 15 GREAT SAFFRON HILL, E.C. 1.											Time to come to rest		
Mod 155	Portable repulsion type with knife-edge pointer and mirror scale	89	133	178 × 181 × 83	150 v.	150	2000	250	0·5	1·2	2·5	—	15 0 0
Mod 155	,,	89	133	,,	10 a.	100	0·013	·023	,,	1·2	2·5	—	14 0 0
Mod 433	,,	69	97·5	148 × 133 × 89	150 v.	150	4550	450	0·75	0·8	3	—	12 15 0
Mod 433	,,	69	97·5	128 × 133 × 89	10 a.	100	0·009	0·010	,,	1·2	3	—	12 0 0

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NOTE ON SHIELDED NON-INDUCTIVE RESISTANCES.

BY L. HARTSHORN, A.R.C.S., B.Sc., D.I.C., AND RAYMOND M. WILMOTTE, B.A., of the National Physical Laboratory.

[*MS. received*, 19*th May*, 1926.]

ABSTRACT. The residual inductance of a "non-inductive" resistance coil of high value (10,000 ohms or more) changes appreciably with changes of its capacity to earth, and thus it is necessary to shield such coils in precision work. The coil thus becomes a three-terminal device, and it is necessary to define exactly what is meant by its impedance. It is shown that in practice there are three possible values for the impedance of any coil, which are important in bridge and many other measurements. The effect of capacity to screen on these values is pointed out, and a simple equivalent network for the coil is indicated.

NON-INDUCTIVE resistances of the order of several thousand ohms are becoming common laboratory standards owing to the increasing importance of measurements at telephonic frequencies and the increasing accuracy required at commercial frequencies. It is important in many cases to know the value of the phase angle of these so-called non-inductive resistances. In the case of high resistances, say, of several thousand ohms, the effect of capacities becomes an important and often dominating factor of the quadrature component of the pressure across the resistance, and care must be taken that these capacities are independent of neighbouring objects. This necessitates surrounding the resistance with a conducting screen maintained at some definite potential, and it becomes necessary to consider the effect of capacities to the screen on the residual inductance.

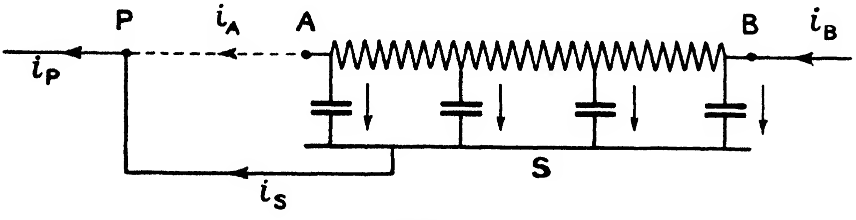


Fig. 1

We must now define exactly what is meant by the impedance of a screened resistance standard. Consider the resistance *AB* (Fig. 1), which we will assume completely surrounded by the screen *S*. This screen is connected to source of constant potential, generally to earth, and we shall confine our attention to this case. The impedance of any element of a circuit is defined as the ratio of the voltage across the element and the current through it. The current through the resistance *AB* for a given potential difference across it cannot, however, be expressed as a single definite value, since, owing to distributed capacity effects, the current is not the same in every portion of the coil. In practice we are only concerned

with the current flowing in at one terminal, say A, and that flowing out of the other, B, but it is easy to see that these currents are not merely functions of the potential difference between A and B. In general, they depend also on the absolute potentials V_A or V_B, since the capacity currents flowing to the screen will vary as this potential varies, even if the potential difference $V_A - V_B$ remains constant. Thus it is only possible to assign a definite value to the impedance of AB by adopting some arbitrary definition of impedance which imposes a definite value to V_A or V_B. We shall assume as our condition that the point A is kept at earth potential, though not necessarily directly connected to earth, as this is the condition most frequently used in bridge measurements. The point P is some other point of the circuit, which is directly connected to earth, so that there is no difference of potential between P and A. Now there is a capacity between each element of the resistance coil and the screen. In the diagram this is represented by a few condensers. Let i_B be the current flowing in at B. Capacity currents will flow from each element of the resistance to the screen. The sum of these currents i_S will return to the circuit at P, so that we have

$$i_B = i_P = i_A + i_S.$$

Now defining* the impedance of AB as the potential difference, V, between A and B, divided by the current at A or B, we obtain two values for the impedance given by

$$Z_{AO} = \frac{V}{i_A}$$

and

$$Z_{AS} = \frac{V}{i_B} = \frac{V}{i_A + i_S}.$$

If now B is kept at earth potential instead of A, the current distribution will be different unless perfect symmetry exists in the construction of resistance coil and screen, which is unlikely. Thus two other values for the impedance are obtained

$$Z_{BO} = \frac{V}{i_B'},$$

and

$$Z_{BS} = \frac{V}{i_B' + i_S'}.$$

It will be shown, however, that Z_{AO} and Z_{BO} are identical, and therefore each may be represented by Z_O, so that, as long as one terminal is kept at earth potential, there can only be three values of the impedance, namely the two values Z_{AS}, Z_{BS} when the current considered includes the earth current i_S, and one value Z_O when the earth current is not included.

In practice this reduces to:

(1) The impedance is Z_{AS} when A is directly connected to the screen.

(2) The impedance is Z_{BS} when B is directly connected to the screen.

(3) The impedance is Z_O when either A or B is kept at earth potential, but is not directly connected to earth.

To prove that $Z_{AO} = Z_{BO}$, consider the simple case of Fig. 2. It is here assumed that there is only one capacity C to earth, the impedances on each side of C being represented by $R_a L_a C_a$ and $R_b L_b C_b$. The effective impedance Z_a between A and C can be shown to be, if we neglect products and higher powers of L_a and C_a,

$$Z_a = R_a + (L_a - R_a^2 C_a)\,\alpha \qquad \text{......(1)},$$

where

$$\alpha = 2\pi\,(\text{frequency}) \times j.$$

* A somewhat similar definition is used by Silsbee, *Bull. Bureau Stds.* **20** 489, and also by R. M. Wilmotte in *Phil. Mag.* 1926. Vol. 2, p. 65.

Similarly $$Z_b = R_b + (L_b - R_b^2 C_b)\,\alpha \qquad \text{......(2).}$$

Now $$i_S = i_A Z_a C\alpha.$$

Therefore $$i_B = i_A (1 + Z_a C\alpha).$$

But $$V = Z_a i_A + Z_b i_B$$
$$= i_A (Z_a + Z_b + Z_a Z_b C\alpha).$$

Therefore $$Z_{AO} = Z_a + Z_b + Z_a Z_b C\alpha \qquad \text{......(3).}$$

It will be noticed that no approximation has been made in obtaining equation (3). Since this equation is symmetrical with regard to Z_a and Z_b it is obvious that $Z_{AO} = Z_{BO}$.

It should be noticed, incidentally, that the symmetry of equation (3) is absolutely independent of the values of Z_a and Z_b. These might be resistances, capacities, self and mutual inductances, or combinations of these. The result that $Z_{AO} = Z_{BO}$ would still hold.

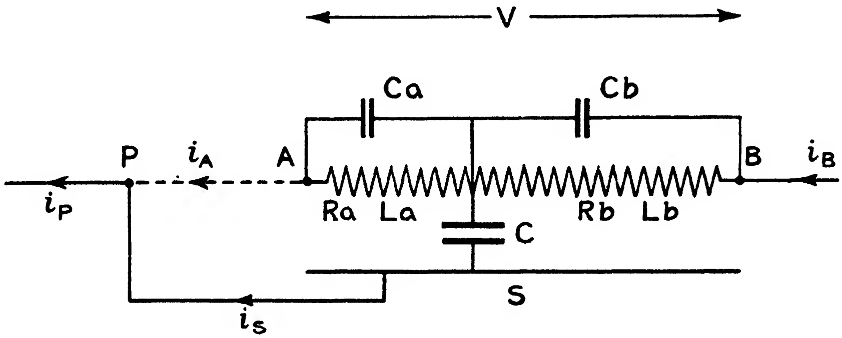


Fig. 2

The process can be made more general by putting an unlimited number of condensers such as C, when it can be shown, that the equation for Z_O is symmetrical so long as either A or B are kept at earth potential.

This result was tested experimentally with a 10,000 ohm resistance. The residual inductance was measured on a bridge with a Wagner earth, so that the terminals were not directly connected to earth. The resistance was completely shielded. The residual inductance was measured firstly with terminal A, then terminal B, at earth potential. The arrangement was then made asymmetric by putting a condenser of $50\mu\mu$ F. between the screen and a tapping point dividing the resistance in the ratio 1 : 9, and the measurements repeated. The values are given in Table I.

Table I

Terminal at earth potential	Condition	Residual inductance, millihenries
A	Without condenser	$0{\cdot}5_0$
B	,,	$0{\cdot}5_3$
A	With condenser	$0{\cdot}9_5$
B	,,	$0{\cdot}9_9$

It will be noticed that the difference in the measured inductance obtained by keeping first A then B at earth potential is very small, and about equal in both cases. This difference is considered to be due to the change in the position of the leads necessitated by the reversal of the resistance.

By means of equations (1), (2) and (3), we obtain as a first approximation when the terms $L_a L_b C_a C_b$ are small

$$Z_O = R_a + R_b + (L_a + L_b - R_a^2 C_a - R_b^2 C_b + R_a R_b C)\,\alpha \qquad \text{......(4).}$$

From this it is seen that the terms containing C_a and C_b are negative, while that containing C is positive. This is a very useful property for, by judicious use of small external condensers, the residual inductance can be made zero. If a resistance is found, when constructed, to have a positive residual inductance, this can be balanced by a condenser across it, while, if the value of the residual inductance is negative, a condenser from some point (not at the ends) of the resistance to screen can make its value zero.

These remarks only apply to Z_O; the imaginary part of both Z_{AS} and Z_{BS} is always rendered more negative, wherever condensers are added.

We shall now see how these considerations affect bridge measurements. Consider the four armed bridge in Fig. 3. We shall suppose that Z_{AB} is a non-inductive resistance and whatever conclusions apply to it will also apply to other non-inductive resistances in the other arms of the bridge.

When the bridge is balanced, we have

$$Z_{AB} . Z_{CD} = Z_{BC} . Z_{DA}.$$

This holds when the impedances are defined in relation to the current at the telephone end, for this current will be common to two arms of the bridge.

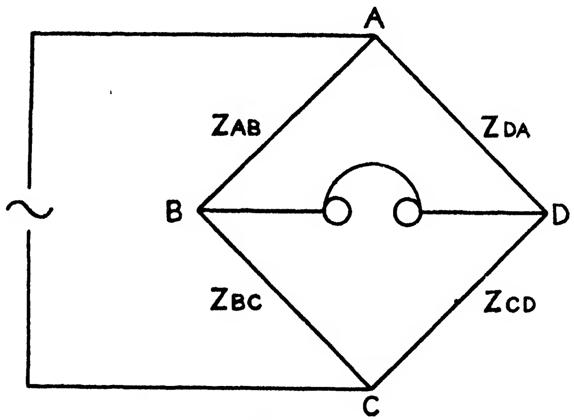


Fig. 3

Two cases are of practical importance.

The first occurs when one corner of the bridge, say A, is directly connected to earth. The shield of AB is also earth connected and is thus directly connected to A, and the impedance will be Z_{AS} as defined above, since the current at B is the same as that at A (Fig. 3) and includes the current flowing to the screen.

The second case occurs when a Wagner Earth Point is used. By this means the point B is kept at earth potential without being directly connected to earth. The screen of AB is directly connected to earth, so that the current at B does not include the current to screen, and the effective impedance of the arm AB is now Z_O.

It is to be noted that by using such a bridge the three values of the impedance of the shielded resistor AB may readily be determined. In each case the bridge measures the impedance with reference to the current at B.

(1) When the screen is directly earthed, Z_O is measured as explained above. Reversing the resistance in the bridge does not change its effective impedance.

(2) If the screen is connected to A (and not earthed), the current at B includes i_S and thus Z_{AS} is determined. The capacity current from the screen to earth does not reach B and thus does not affect the result. Reversing the resistance (with the screen still connected to A) does not affect the measured impedance, since the current measured still

includes the capacity current between coil and shield, and there is no capacity current between the screen and earth, since the screen is now at earth potential.

(3) By connecting the shield to B instead of to A the impedance Z_{BS} is determined in exactly the same way.

It is very important to take particular care regarding the value of impedance, which should be used in any special case.

Two typical shielded inductionless resistances have been measured, and the values given in Table II show the order of differences which are to be expected in the case of well-made resistances.

Table II

Resistance	Condition of use	Effective self-inductance, millihenries
10,000 ohms X	Z_O	-0.3_3
	Z_{AS}	-0.9_4
	Z_{BS}	-1.0_7
10,000 ohms Y	Z_O	$+0.5_0$
	Z_{AS}	-1.2_7
	Z_{BS}	-3.1_6

The measurements were made on a simple unequal arm bridge in the manner described above. The values were obtained in terms of a standard 1000 ohm resistance, the effective inductance of which had been determined in terms of a calculable standard.

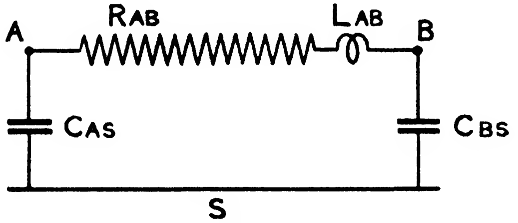


Fig. 4

Since a resistance standard used in this manner possesses three definite values of impedance and only three, it follows that it may be completely represented by the simple network of Fig. 4, where to a first approximation

$$Z_O = R_{AB} + jwL_{AB}$$
$$Z_{AS} = R_{AB} + jw\,(L_{AB} - R^2_{AB}.C_{BS})$$
$$Z_{BS} = R_{AB} + jw\,(L_{AB} - R^2_{AB}.C_{AS}).$$

In some respects it is more convenient to deal with the three constants L_{AB}, C_{AS}, C_{BS} than it is to consider the three possible values of the impedance. The values of these constants for the two coils X and Y (Table II) are given in Table III.

Table III

Coil	L_{AB} mH.	C_{AS} $\mu\mu$F.	C_{BS} $\mu\mu$F.
X	-0.3_3	$7._4$	$6._1$
Y	$+0.5_0$	$36._6$	$17._7$

A MACHINE FOR RATING INCANDESCENT LAMPS.

By C. G. EDEN and N. R. CAMPBELL. Communication from the Staff of the Research Laboratories of the General Electric Company, Ltd., Wembley.

[*MS. received, 23rd August*, 1926.]

ABSTRACT. A machine is described for rating lamps (i.e. determining the voltage at which they will burn at a prescribed efficiency), by means of the method of photoelectric colour matching of which an account has been given previously in this *Journal*.

The machine enables lamps to be rated with a mean error of 0·13 per cent. in volts by a single operator at a speed of about 200 lamps per hour. If it is only required to determine whether the rating falls within 2 per cent. of a prescribed voltage, a speed of 350 lamps per hour can be attained by two operators. If the machine were modified by making certain motions automatic, the same speed could probably be obtained by one operator, who would merely insert and remove the lamps and watch the deflexions of an electrometer.

(1) Principles of Construction

The method of photoelectric colour matching which has been described previously in this *Journal** was developed originally in order to obtain sensitivity and accuracy greater than those of visual methods. An application is now described in which accuracy is sacrificed in order to obtain greater speed. Speed is of great importance when large numbers of lamps have to be "rated," i.e. the voltage determined at which they will burn with a prescribed efficiency. An exact determination of this voltage is often not required; all that is needed is a knowledge of within which of a number of ranges (e.g. 195–205, 205–215, etc.) the rated voltage falls. A sensitivity of 2 per cent. in voltage is, therefore, sufficient; since the method as previously described has a sensitivity of 0·03 per cent., it is clear that there is abundant room for the attainment of speed at the expense of accuracy.

The speed may be limited by three factors:

(1) The period required to make an estimate of photoelectric balance. In the original apparatus with a 20 watt vacuum lamp this period is about 2 seconds for a single estimate of the required accuracy or 4 seconds for the pair of estimates needed to determine whether the balance lies within a given range; for lamps of greater intensity or efficiency it would be somewhat less.

(2) The period required to introduce the lamp into the photometer; in the original apparatus this was about 30 seconds.

(3) The period required for the lamp to take up a steady state. If the lamp had been burnt for some time previous to the test, this period is of the same order as (1), when only 2 per cent. accuracy is required; but when the lamp is burnt for the first time, it is about 3 minutes. If, therefore, lamps are to be tested immediately after manufacture, the order of importance of the factors is (3), (2), (1); if they are to be tested after ageing (2) is predominant.

A limit is set to (2) because the lamp under test has to be placed in a light-tight enclosure for three reasons. In order to avoid errors due to the exact position of the filament relative to the photoelectric cells it is necessary to use diffused rather than direct light; it is undesirable in any case to work in a dark room; and, if the lamps are to be aged before test in the neighbourhood of the apparatus, it is impossible to do so. The first reason requires that the enclosure shall be substantially the same for all lamps. In order to introduce the lamps quickly into such an enclosure, it was found more convenient to build the enclosure round the lamps rather than to move them into a fixed space.

* Research Staff of the G. E. C. Wembley, *J. Sci. Insts.* **2** (1925) 177, and **3** (1925) 2.

(2) Description of the Machine

Figs. 1 and 2 are diagrammatic drawings (not to scale) of a machine that has been constructed in accordance with these principles. Six lamps, 1, 2, 3, 4, 5, 6, are held in lamp-holders attached to spokes of the rimless wheel *a*. The number of these lamps is determined by the requirement that the period (3) shall not be greater than that occupied in a revolution of the wheel during which all the lamps are tested. Six lamps are sufficient for this purpose if the lamps to be tested have already been aged; if new lamps were to be tested about 30 lamps would be required. The increase in the number of lamp positions would involve no alteration other than that of the size of the wheel.

The wheel *a* is mounted on a bearing near the top of the fixed support *b* on the base *c*; it can be turned by hand to bring each lamp in turn above the photometric apparatus (position VI in Fig. 2). The lamps are put on and taken off at position I (Fig. 2), where they are not supplied with current. In positions II, III, IV, V they are connected to a supply at approximately constant voltage and are thereby brought to a steady state. In position VI they are connected to a supply which can be regulated for rating. These changes are made by means of brushes *d*, *d* (Fig. 1), in contact with commutators *e*, *e*. Each commutator is divided into three parts, e_1 being dead, e_2 connected to the constant supply, and e_3 to the regulated supply.

The lamp-holders are surmounted by caps $f_1 \ldots f_6$, each of which in turn becomes the lid of a light-diffusing box when the tube *g* is raised by the vacuum lift *h*. The bottom of the box is the top of the rotating housing of the two photoelectric cells, i_1, i_2. The enclosure is light-sealed when *g* is raised by the overhanging cap *f* at the top and by the labyrinth *p* at the bottom. *g* is painted black outside and white inside, while the top of the rotating housing and the caps *f* are painted black; accordingly the only part of the enclosure which reflects any appreciable amount of light is common to all lamps and variations in the diffusion of the light from different lamps by differences in the enclosure are avoided. The direct rays from the lamp are cut off from the photoelectric cells by the white screen *j*. If, therefore, the lamps are geometrically similar and are similarly placed in the enclosure, that enclosure should act in the same manner as the ideal photometric sphere, although it departs from it so widely in form. The rotation of the cells serves, as in the previous apparatus, to make the approximation to the ideal condition still closer.

The vacuum lift *h* is controlled by a foot pedal connected to a valve (not shown), and is worked by the operator who turns the spoked wheel.

The arrangement of the photoelectric cells is essentially similar to that previously described; but the gear for moving the adjusting shutter while the box is rotating is not used. A method of working is adopted in which accurate adjustment of the shutter to give a balance at a prescribed efficiency is unnecessary; and there is no serious inconvenience in making the adjustment when the housing is at rest and the tube *g* lowered. The sodium cell is, therefore, partially covered by a simple shutter *x* rotating round a pin on the top of the housing; the rubidium cell is covered by a No. 9 Wratten filter *y*, on which ink can be placed if it is necessary to reduce further the current from this cell.

The housing is driven by a belt from an electric motor (not shown). The battery connexions are made through slip-rings *m*, *n*, the connexion to the electroscope *q* through a central rod dipping in a mercury cup (not shown), and a fixed shielded conductor *o* which can be earthed by the switch *r*. The insulation of this conductor is of sulphur.

The electrometer is a Lindemann quartz needle instrument* made by the Cambridge Instrument Company. It reads very quickly, and its zero is remarkably stable in spite of

* F. A. and A. F. Lindemann and T. C. Keeley. *Phil. Mag.* XLVII, March 1924.

changes of temperature and level; it is, therefore, particularly well suited for determining a balance. Movements of the needle are observed by projecting its image on a screen *s* by means of the lamp *t*, lens *u*, microscope objective *v* and mirror *w*.

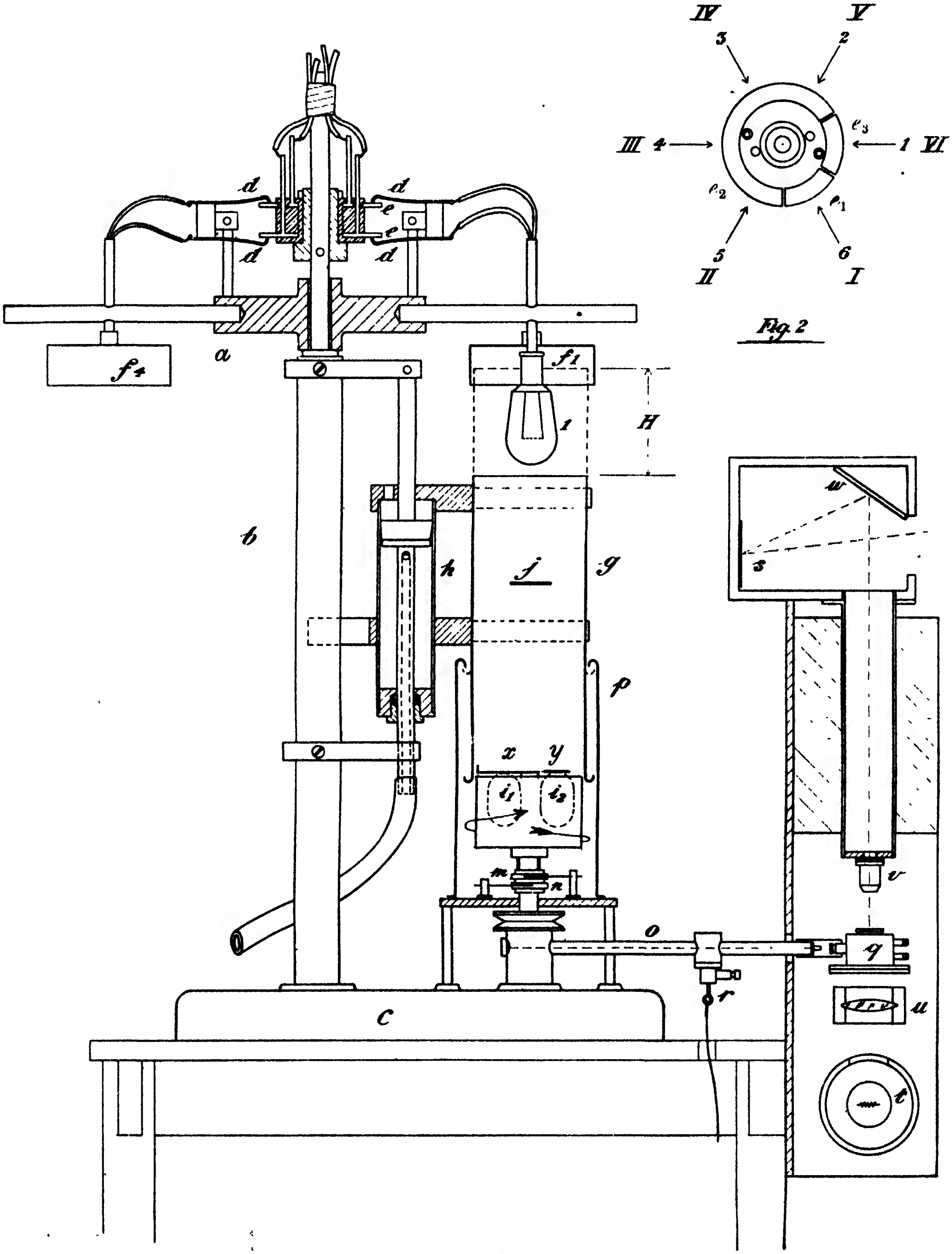


Fig. 2

Fig. 1

(3) Calibration

The machine has to be calibrated by the use of standard lamps of which the rated voltages are known and which are of the same wattage and filament form as the lamps to be tested. If the problem is to determine exactly the voltage at which a number of lamps have the

same efficiency as the standard lamp run at (say) 200 volts, the standard is introduced into the machine and the shutter set so that a balance is obtained when the voltage is 1 or 2 per cent. greater than 200. The voltmeter is now adjusted by a rheostat in series with it until it reads 200. The test lamps are now introduced and the voltage on them varied till a balance is obtained; their rated voltage is then that read on the adjusted voltmeter. This is true in virtue of the law of equivalence*, which is accurately valid for vacuum lamps of similar type; it is not accurately true for gas-filled lamps, but departures from it are too small to be appreciable when a limit to sensitivity is set in any case by the scale divisions of a voltmeter.

The machine is affected, like all photoelectric apparatus, by a slight drift; the voltage required to balance does not remain perfectly constant. If the greatest accuracy is required, the drift must be corrected by putting the standard round the machine at regular intervals and readjusting the voltmeter. But the drift never causes changes of more than 1 per cent. in the rated voltage; if such an error is permissible, the shutter and the shunt can be set once for all in the positions appropriate to lamps of a given type, and the machine used from day to day without alteration.

If the problem is merely to determine whether the rated voltage lies within certain limits, the limiting voltages are applied in succession; the lamp will pass if the corresponding deflections are in opposite directions. A standard is used in calibration in the same manner, the limiting voltages being adjusted by the law of equivalence to avoid the necessity of very careful setting of the shutter. Circuits whereby this adjustment can be made with the necessary accuracy are easily devised.

(4) Results

Some tests were made of the speed and accuracy obtainable with the machine. A limit is set to the possible accuracy by the constancy of the lamps themselves and the divisions of the voltmeter. In commercial vacuum lamps these limits are about the same, namely 0·1 per cent.; in gas-filled lamps the variations in the performance of the lamp make measurements to less than 0·5 per cent. insignificant. About 15 seconds were required for rating a 40 watt vacuum lamp to 0·1 per cent.; the mean root square error of a determination, obtained by making several sets of measurements on the same series of 50 lamps, was 0·13 per cent.; and the values obtained differed by about the same mean error from those given by the photometer designed for accuracy and not for speed.

When the photometer was used merely to determine whether the rated voltage lay within 2 per cent. of an assigned value, the pair of readings required took about 3 seconds. When an assistant was employed to insert and remove the lamps, they could be rated within these limits at the speed of 300–350 an hour. It would probably be possible to maintain this speed without using two observers by making the following motions automatic:

(1) Lowering the sleeve.
(2) Moving the table to the next position.
(3) Raising the sleeve.
(4) Setting the voltage to the lower limit.
(5) Insulating the electroscope for about 1 second and earthing again.
(6) Setting the voltage to the higher limit.
(7) Repeating (5).

The observer would then merely insert and remove the lamps and see whether the two deflections obtained in (5) and (7) were in opposite directions. But this further development has not yet been carried out.

* *J. Sci. Insts.* **3** (1925) 8.

A comparison may be made with visual methods. In the routine photometers employed for life-test work in these laboratories, two observers can rate lamps at about 200 an hour by observing the current and lumens at a given voltage.

The mean error, determined by repeating the observations on the same batch of lamps, is 0·9 per cent. in efficiency at a given voltage which corresponds to 0·4 per cent. in volts at a given efficiency. Both the accuracy and the speed are therefore considerably lower. No allowance is made here for the time necessary to reduce the observations to the form in which they are finally to be presented, for this time depends on the method of presentation; but since the visual method requires the observation of two quantities and the photoelectric of only one, the advantage is likely always to lie with the latter.

AN INTERFERENCE APPLIANCE FOR THE ACCURATE COMPARISON OF LENGTH GAUGES. By F. H. ROLT, B.Sc., A.C.G.I., AND C. H. KNOYLE. From The National Physical Laboratory.

[*MS. received*, 5*th June*, 1926.]

ABSTRACT. This paper describes an apparatus for intercomparing two or more length gauges, of nominally equal length, by interference methods. It consists of a tilting lever, resting on three ball feet, two of which are supported from the base of the apparatus, whilst the third rests in turn on the various gauges to be compared. The lever carries at the top a polished flat steel surface, over which an optical proof plane can be adjusted to give the desired pitch and direction to the interference fringes which appear when the apparatus is suitably illuminated with monochromatic light. A simple optical scheme is also described. The comparison of the gauges is effected by placing them in turn under the third foot of the tilting lever, and counting the number of fringes, in whole numbers and tenths, which fall within a given space. The difference between the gauges in inches is then $K\frac{n_1 - n_2}{2}\lambda$, where n_1 and n_2 are the number of fringes produced by each gauge in turn, and λ is the wave-length (in inches) of the radiation used, and K is a constant depending upon the magnification of the lever arrangement.

This apparatus consists in principle of a horizontal lever, the inclination of which is controlled by the thickness of a gauge placed under one end. The tilt of the lever is measured by observation of straight interference fringes formed in monochromatic light between the upper surface of the lever and a fixed optical flat. If a number of gauges are placed in succession under the lever, a comparison of their lengths can be obtained from the corresponding interference patterns.

The apparatus as made in an experimental form is shown diagrammatically in Fig. 1. The cross-shaped lever, A, has two points, E, resting in a hole and a groove in the horseshoe bracket, D, which is clamped to the vertical post of the apparatus. The short arm of the lever is furnished on the underside with a steel ball, B, at a distance, d, from the axis of rotation. This ball rests on the upper surface of a gauge, G, which is wrung down to the sliding block, H. On the top of the lever is attached an accurately flat polished steel plate, C, and above this is an optical flat, I, supported on three levelling screws having a fine pitch, or other method by which a sensitive adjustment may be made. The interference fringes, used to determine the relative length of the gauges, are obtained by viewing the flat in parallel, normal, monochromatic light, such as the green radiation from a mercury vapour lamp.

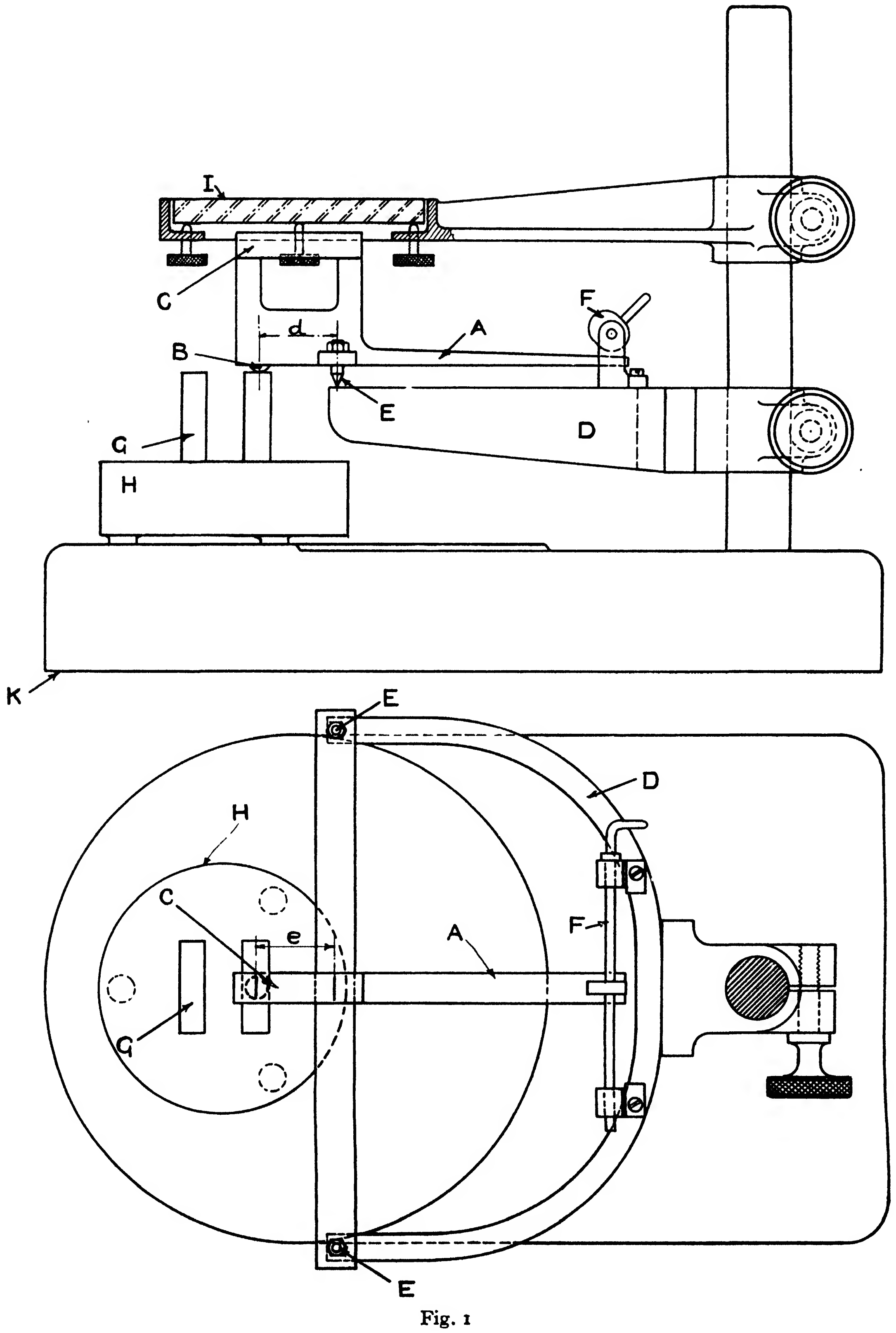
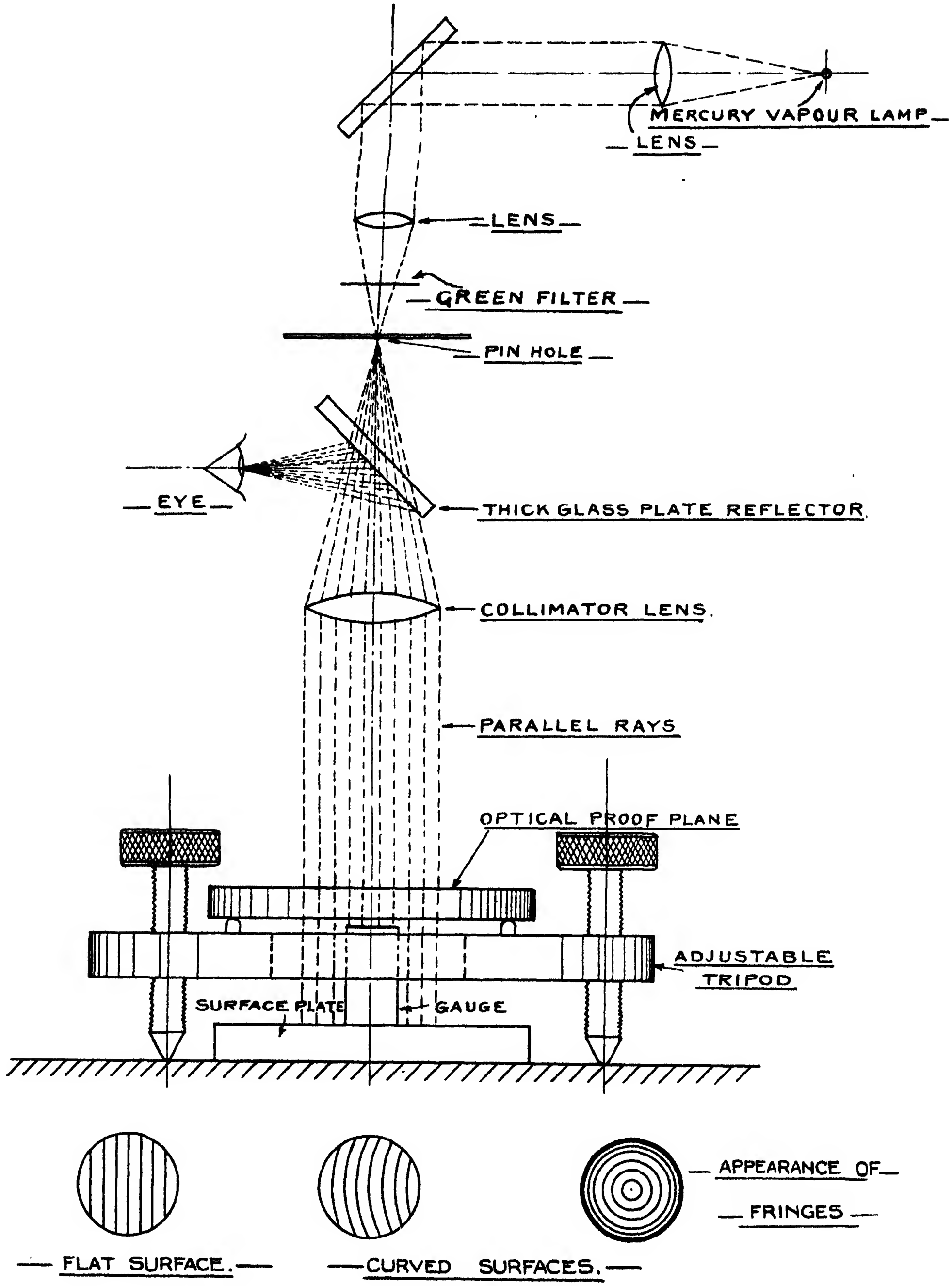


Fig. 1



SCHEME OF INTERFERENCE APPARATUS FOR TESTING FLATNESS OF GAUGE SURFACES.

Fig. 2

A simple optical scheme for the purpose is shown in Fig. 2*. Light from a mercury vapour lamp is focused on to a pin hole, about 1 mm. diameter, in a brass plate with or without the prism or other reflector shown in the diagram. A gelatine light filter placed in front of the pin hole serves to isolate the green radiation from the lamp. The pin hole in its turn is placed at the focus of the collimating lens, which thus throws a parallel beam normally on to the proof plane. If the plane is adjusted by means of the three levelling screws so as to be very slightly inclined to the surface of the plate *C*, dark interference fringes will be produced, which can be viewed and counted by means of the clear glass reflector placed at an angle of 45° to the optical axis of the system between the pin hole and the collimator lens. These fringes will take the form of parallel equidistant bands, the direction of which can be varied by adjusting the proof plane.

The sliding block, *H*, which stands on three feet, has its upper surface lapped accurately flat and parallel to the plane through the feet. The block is free to slide on a film of paraffin on another flat surface, which may be produced on the base, *K*, of the machine, or may take the form of one of the good class lapped surface plates which are available on the market.

To make a comparison between two or more nominally equal gauges, they are wrung down on to the block, *H*, as shown, and the ball point of the lever is lowered on to the surface of one by means of the cam attachment, *F*. The optical flat is then adjusted until a small number of interference fringes are formed between it and the steel surface, *C*. The flat is finally set so that the interference bands are brought parallel to two lines engraved on the surface, *C*, at a distance apart, *e*, equal to *d*. The number of bands, in whole numbers and tenths, occupying the space *e* is then counted. The ball point is then raised off the gauge by means of the cam, and by sliding the table, *H*, the second gauge is brought into position for measurement. Having lowered the ball on to this gauge, the number of bands is again counted.

If the number of interference bands for the two gauges are respectively n_1 and n_2, the difference in their lengths is given by $(n_1 - n_2) \cdot \frac{\lambda}{2}$, λ being the wave-length of the monochromatic light used. For Hg green, λ equals 0·546 μ, i.e. 0·0000215 inch, so that a difference of one band represents closely one hundred-thousandth of an inch.

As regards the sign of the difference, this can be readily decided by noting whether the number of bands increases or decreases as the ball is gently raised off the gauge surface. This device has been found to be easily capable of giving reliable results to 0·000005 inch, provided that the flatness of the gauges being tested is good, but it is interesting to note that the interference lever is capable of greater sensitivity by reducing the distance, *d*, to 1/2, 1/5 or even 1/10th of *e*.

The principle could also be applied, possibly, for determinations of coefficients of expansion. It would also serve as a means of testing accurate spirit levels.

* This illustration shows the optical scheme as used for testing the flatness of the surfaces of steel gauge blocks.

THE VALVE BRIDGE. A NEW METHOD OF MEASURING THE ANODE IMPEDANCE AND VOLTAGE FACTOR.

By W. BAGGALLY.

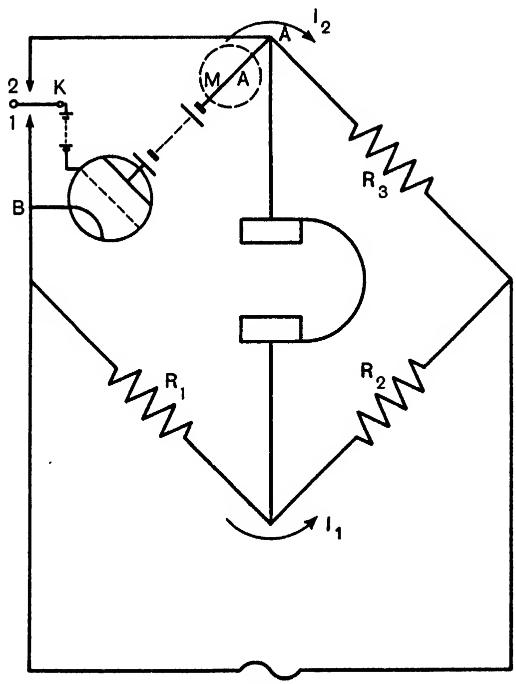
[*MS. received, 5th July*, 1926.]

ABSTRACT. The arrangement to be described consists of an A.C. bridge; the triode under test occupying one of the arms.

A standard Post Office or similar resistance box is used in the measurements, the other apparatus required being the usual A.C. source (buzzer or valve generator) and some form of detector, such as a telephone or vibration galvanometer.

VARIOUS methods have been developed from time to time for the purpose of measuring the gradients of the grid-anode and anode-anode characteristic curves or some function of these gradients, such as the Appleton slopemeter, Miller's circuits and others.

These arrangements, while excellent in cases where the number and frequency of the tests undertaken merit the setting apart of a special bench and set of instruments more or less permanently wired up for valve measurements, are as a rule somewhat inconvenient



where a few valves only, at fairly long intervals, are to be tested (the various instruments being required for other work between the tests), as it often takes at least two hours to set up some of the comparatively complex circuits often employed.

The writer therefore worked out, some eight months ago, the circuit shown in the diagram.

Referring to this diagram, R_1, R_2 and R_3 may consist of the arms of a Post Office box, the valve being connected in the position usually occupied by the unknown resistance; it will be seen, therefore, that the arrangement is very easily and rapidly connected up.

Having made all connections as shown, and adjusted the filament, anode and grid batteries to the potentials at which it is desired to determine the constants of the tube, the key K is put in contact with the lower or first stud, and the bridge balanced.

Then we have

$$Z = \frac{R_3 R_1}{R_2} \qquad \ldots\ldots(1),$$

where Z is the anode impedance, and R_1, R_2 and R_3 are the resistances of the arms for this first balance.

K is now transferred to the stud marked 2, and the bridge again balanced; then

$$\mu = \frac{ZR_2' - R_3'R_1'}{R_3'R_1'} \qquad \ldots\ldots(2),$$

where μ is the voltage factor, and the dashes signify that the resistances are those obtained for the second balance.

The mathematical theory of this bridge will now be discussed, so as to lead up to the consideration of certain practical details which it is desirable should be attended to in using the arrangement.

Let M be the mutual conductance of the valve, E_a and E_g the alternating parts of the anode and grid voltages respectively, and I the alternating part of the anode current.

Then if I_1 and I_2 are the alternating currents flowing in the lower and upper pairs of arms of the bridge when it is balanced, and if all these currents and voltages are small, then for the first balance, since there is no alternating grid potential with K in position 1, and since Z is the A.C. resistance of the valve,

$$Z = \frac{R_3 R_1}{R_2} \qquad \ldots\ldots(1),$$

this being the equation for Z given above.

From the elementary theory of triodes we have

$$I = ME_g + \frac{E_a}{Z} \qquad \ldots\ldots(3),$$

and upon referring to the diagram it will be seen that owing to the mode of connexion of the valve,

$$E_g = E_a \qquad \ldots\ldots(4),$$

$$I = I_2 \qquad \ldots\ldots(5),$$

so that from equations (3), (4) and (5) we derive

$$I_2 = E_a\left(M + \frac{1}{Z}\right) \qquad \ldots\ldots(6),$$

or transposing for E_a,

$$E_a = I_2 \frac{Z}{MZ + 1} \qquad \ldots\ldots(7).$$

Now when the bridge is balanced, the drop across the valve is equal to that across R_1', therefore

$$I_2 \frac{Z}{MZ + 1} = I_1 R_1' \qquad \ldots\ldots(8),$$

similarly

$$I_2 R_3' = I_1 R_2' \qquad \ldots\ldots(9),$$

dividing equation (9) by (8) to eliminate I_1 and I_2, we get

$$\frac{R_3'}{Z}(MZ + 1) = \frac{R_2'}{R_1'} \qquad \ldots\ldots(10),$$

but

$$MZ = \mu \qquad \ldots\ldots(11),$$

therefore $$\frac{R_3'}{Z}(\mu + 1) = \frac{R_2'}{R_1'} \qquad \text{......(12)},$$

from which $$\mu = \frac{ZR_2' - R_3'R_1'}{R_3'R_1'} \qquad \text{......(2)},$$

this being the second equation given at the beginning of the paper.

Of course, if the mutual conductance of the triode is required, it will only be necessary to multiply the expression on the right of equation (2) by $10^6/Z$, which will express the mutual conductance in micromhos.

It is often convenient when working with this bridge, to make R_2 equal to R_3, in which case the equations (1) and (2) take the simpler forms

$$Z = R_1' \qquad \text{......(1 } a\text{)},$$

$$\mu = \frac{Z - R_1'}{R_1'} \qquad \text{......(2 } a\text{)},$$

so that the bridge becomes direct reading in Z and the arithmetic involved in the evaluation of μ may usually be performed mentally.

Coming now to practical considerations, it may first be noted that if the E.M.F. of the A.C. source is too great, the first harmonic will be audible (if a telephone is being used) after the fundamental has been extinguished by balancing the bridge, and it will be found impossible to eliminate this harmonic by adjusting R_1, R_2 and R_3.

The cause of this phenomenon is to be found in the curvature of the valve characteristic introducing harmonics which are not present in the original A.C. from the generator, these harmonics appearing as voltages in the valve arm; so that it is as if we balanced the bridge in the ordinary way and then introduced a second A.C. generator in series with the valve, and since the valve arm and telephone arm are not conjugate conductors, these harmonic E.M.F.'s cannot be balanced out.

The phenomenon is not usually troublesome, as there is no difficulty in balancing for the fundamental even when the octave is quite powerful, and moreover, it is only necessary to reduce the generator E.M.F. until the portion of characteristic curve explored is sensibly linear, in order to completely eliminate the octave.

It may be mentioned in passing that in consequence of the above property, the bridge has been used by the writer for the purpose of isolating the distortion components of the output from an incorrectly adjusted speech amplifying valve in connexion with work on distortion in amplifiers; the circuit also has other applications, but as the present paper is only concerned with the measurement of valve constants, they cannot be discussed here.

Secondly, it is usually desired to know at what value of steady anode voltage the valve is working.

If we neglect the resistance of the A.C. generator, the resistance between the points A and B external to the valve is given by

$$\frac{R_3 T (R_1 + R_2) + R_1 R_2 R_3}{(R_3 + T)(R_1 + R_2) + R_1 R_2} \qquad \text{......(13)},$$

where T is the resistance of the telephone or other detector, so that from this expression and the value of the anode current, which may be obtained by a milliammeter shown dotted in the diagram, the anode voltage is easily calculated when the anode battery voltage is known.

A source of error possessed by this method in common with most other valve testing circuits, which the writer has not seen pointed out elsewhere, is as follows. When the switch over occurs (most methods involve two observations with different circuit connexions) the steady grid voltage is altered owing to the change in that part of the circuit external

to the valve, so that the second half of the observation is taken at a different grid potential to the first part.

This trouble may be obviated in a very simple way without calculation as follows, both in the present case and in others in which it occurs.

Before commencing the test, the grid is adjusted to the desired potential, the deflexion of the milliammeter (which need not be calibrated) being noted.

On switching over, prior to the second part of the test, the deflexion will, in general, change.

The deflexion is now to be restored to its previous value by adjusting the grid potential, which is thus brought back to its original value; the test then proceeding as usual.

Finally, as to the accuracy of the method, it has been compared against two methods which are well known, that due to Miller, and the method of finite differences; in all cases, the variations were found to be well within the limits of experimental error.

DESCRIPTION OF AN IMPROVED THORNER DAYLIGHT FACTOR METER. By A. K. TAYLOR, A.C.G.I., M.I.E.E., A.M.I.C.E.

National Physical Laboratory.

[*MS. received, 16th June*, 1926.]

For easy and rapid measurement of the daylight factor with an average instrument error not exceeding 5 per cent., the Thorner pattern of meter is a convenient and portable instrument.

The original design provided merely two or three diaphragms of different apertures and had no provision for filters, and all that could be done was to find if the daylight factor was less or more than that corresponding to the diaphragm apertures supplied.

The instrument to be described (Figs. 1 and 2) consists of an internally blackened box C, with a mirror at M, and a lens in an iris diaphragm with scale and index at L. A matt white comparison screen having a small hole with bevelled edges is fixed at S at the focus of the lens.

The mirror is then adjusted so that an image of a small portion of the sky is made to fall on the comparison screen; the brightness of this image is then varied by the iris diaphragm until it appears to be as bright as the test surface T viewed through the hole in S.

The index then gives the daylight factor (due allowance being made for any filters in the mount f). Precautions should be taken when measuring diffused light that the observer himself does not reflect any light on, or obstruct any light from, the test surface.

Theory. It can be shown (vide "Radiation from a Perfectly Diffusing Disc," *Proc. Phys. Soc.* **32**, Part II, Feb. 15, 1920, p. 59, etc.) that the illumination received by one disc from another of equal diameter is sensibly uniform to within 1 per cent. over the whole disc provided that the ratio of the distance to the radius is $\geqslant 10 : 1$.

Hence it may be assumed that the brightness of an image of any object whose maximum dimension is not greater than that of the lens, and which is placed at a distance not less than 10 times the maximum radius of the aperture, will be proportional to the lens aperture. This is equivalent to specifying that the angle subtended at the lens by the object must be $\leqslant 2 \tan^{-1} 1/10$ or $\leqslant 12°$. Therefore, if the field at S is such that $a/F \leqslant 1/10$ (where a is the maximum dimension of the image on the field, and F is the focal length of the lens), this assumption will cause no appreciable error.

Let Φ be the flux of light on the lens L corresponding to the image at S; A, the area of the small portion of the window giving an image at S; r, the radius of lens opening $= d/2$; B, the brightness of the sky; m, the reflection factor of the mirror; t, the transmission factor of the lens; l, the distance from lens to window.

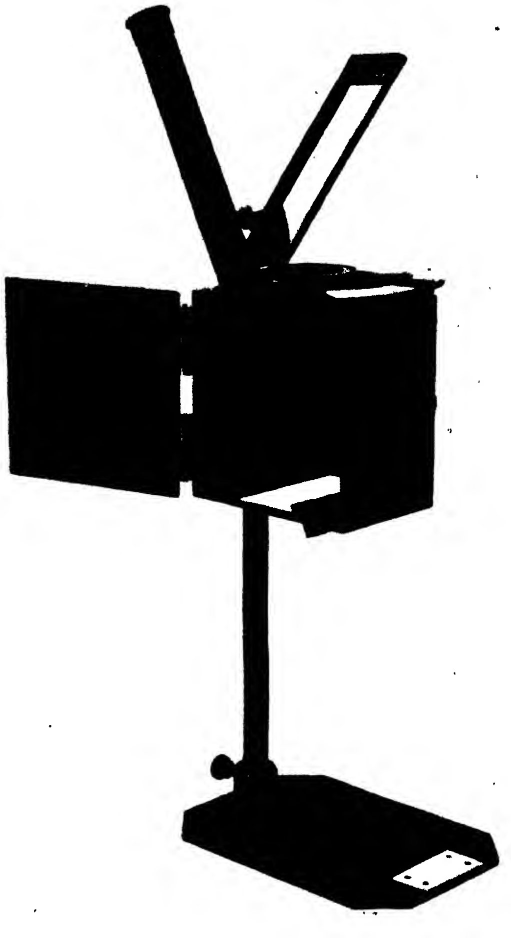


Fig. 1

Then $$\Phi = \frac{mBA\pi r^2}{l^2},$$

$\Phi_s =$ flux transmitted to the screens,

$\therefore\ \Phi_s = t\Phi.$

$$E_s = \text{illumination on screen} = \frac{\Phi_s}{\text{area of image}},$$

also $$\frac{\text{area of window}}{\text{area of image}} = \frac{l^2}{F^2},$$

when F is the focal length of the lens.

Therefore $$E_s = \frac{\Phi_s l^2}{F^2 A} = \frac{mtB\pi r^2}{F^2}.$$

Now the daylight factor (still ratio)

$$\Delta = \frac{2E_p}{E_o},$$

when E_p is the illumination at the point considered and E_o is the illumination due to a hemisphere of sky of uniform brightness B.

Since

$$E_o = \pi B,$$

$$\Delta = \frac{2E_p}{\pi B},$$

and at balance

$$\Delta = \frac{2E_s}{\pi B} = \frac{mtd^2}{2F^2}.$$

If

$$m = \cdot 88\ t = \cdot 90,$$

$$\Delta = \frac{0\cdot 4d^2}{F^2}.$$

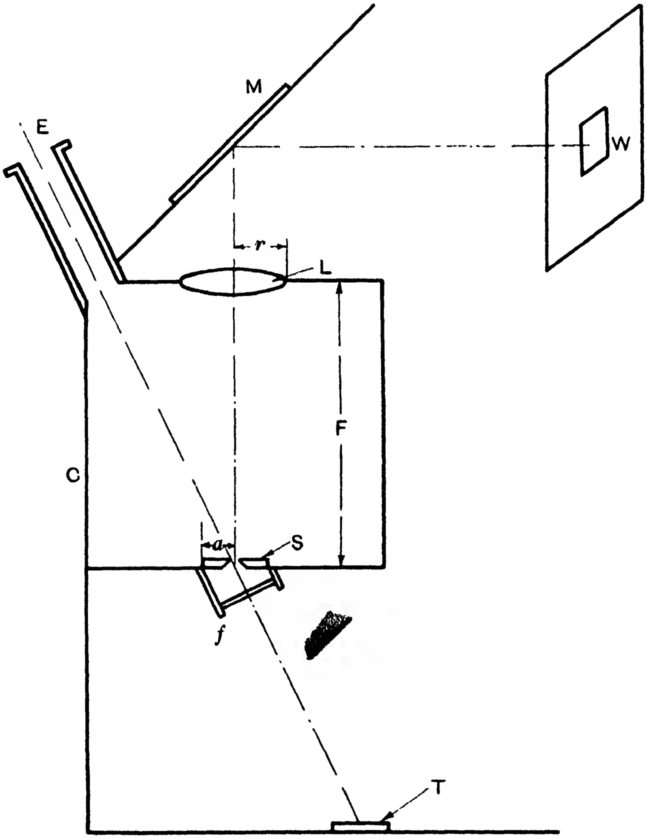


Fig. 2. Diagram of meter

Calibration. To calibrate the instrument it is necessary to have a fairly large source of light of uniform brightness. In order that its uniformity may be checked, the brightness should not be excessive, hence the size of the source must be large in order to obtain sufficient illumination on the test card T at a reasonable distance. Since the sky cannot by any means be depended on for this purpose, an artificial source must be obtained.

The source actually used consisted in a sheet of white flashed opal glass mounted in one side of an internally whitened box (Fig. 3). Electric vacuum lamps with frosted bulbs were

fixed along the edges as shown at *LL*. The opal glass was screened by whitened battens as shown at 4, 1, 5, 8, etc., so that its illumination was due entirely to reflected light. By suitably proportioning the box and the spacing of the lamps it was possible to produce an illumination on the opal glass window such that its brightness did not vary by more than 4 or 5 per cent. over its surface.

The ratio of the brightness of such a source to the illumination produced by it at any point—e.g. one in a plane perpendicular to the plane of the source and in the right projector of one corner—can be calculated in terms of the dimensions of the source and the perpendicular distance of the point considered.

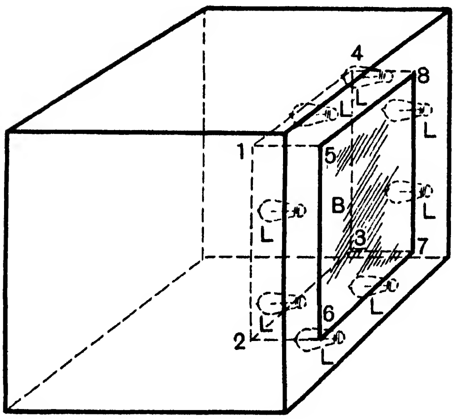


Fig. 3. Window of uniform brightness

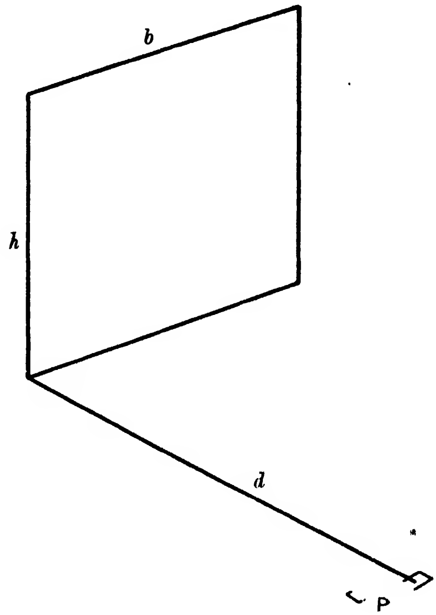


Fig. 4. Diagram of w·-

Let the source have the dimensions shown in Fig. 4, then the ratio of the illun n at the point P in a plane normal to the source and distant d from it, to the brightne. ·e source B is*

$$\frac{E}{B} = \frac{1}{2}\left[\tan^{-1}\frac{b}{d} - \frac{1}{\sqrt{1+\frac{h^2}{d^2}}}\tan^{-1}\frac{b}{d\sqrt{1+\frac{h^2}{d^2}}}\right] = M_h.$$

Now the daylight factor as shown before

$$= \frac{2E_v}{\pi B}.$$

Hence, when balance is obtained,

$$\Delta = \frac{2M_h}{\pi}.$$

Similarly, for the vertical daylight factor,

$$\frac{E_v}{B} = \frac{1}{2}\left[\frac{h}{\sqrt{d^2+b^2}}\tan^{-1}\frac{b}{\sqrt{d^2+b^2}} + \frac{b}{\sqrt{d^2+h^2}}\tan^{-1}\frac{h}{\sqrt{d^2+h^2}}\right],$$

$$E_v = M_v B$$

or $$\Delta = \frac{2M_v}{\pi}.$$

* Vide Bassett Jones, *Illum. Eng. Soc. N.Y.* 5 (1910) 281.

A table and curve (Fig. 5) are given for the horizontal and vertical daylight factors due to a square aperture. (These values may also be obtained graphically by Waldram's Method.)

It may be noticed that for values of n greater than 2, the horizontal daylight factor is equal to the vertical daylight factor divided by $2n$; the error varying from 6 per cent. for $n = 2$ to 1 per cent. for $n = 4$.

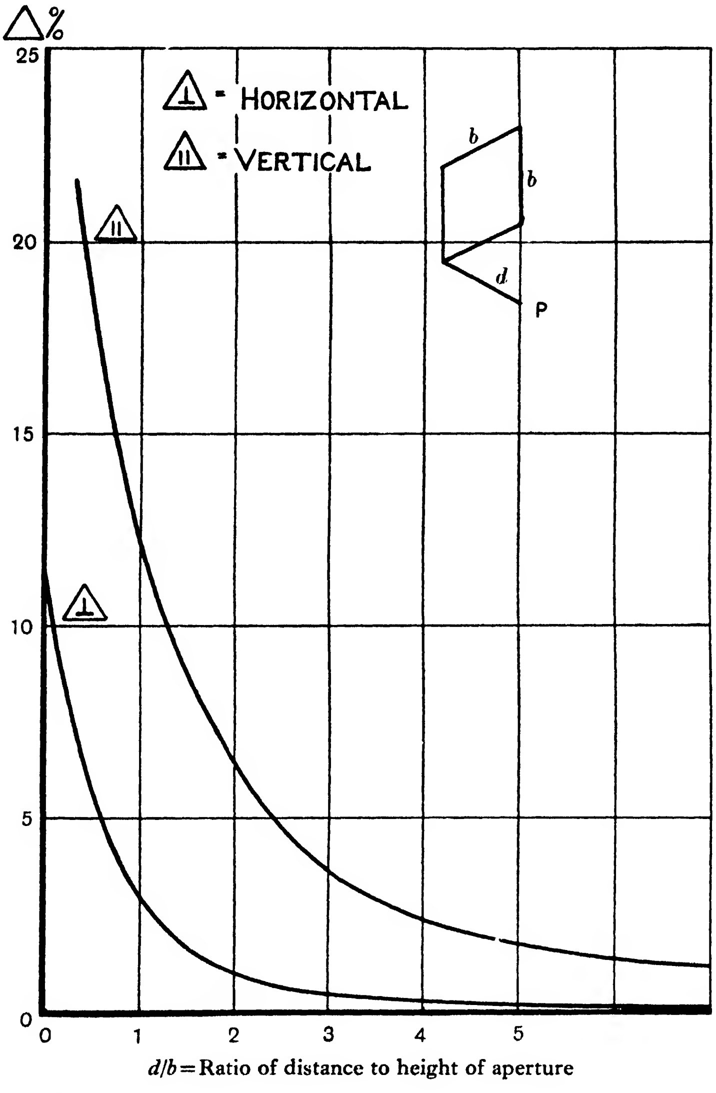


Fig. 5. Daylight factor on horizontal and vertical planes for a square aperture of uniform brightness

The instrument can also be used to compare the indirect illumination received from the walls, ceilings, etc., of a room with that provided directly by the lighting sources. This ratio will depend on the reflection factor of the mural decorations and on the lighting sources, and is a measure of the efficiency of the lighting system as a whole.

To make this comparison, all that is necessary is to adjust the mirror so that an image of some white surface, e.g. a piece of white cardboard, is seen on the screen at S, if readings are taken at various points with direct light on the test card (R_a), and with the direct

illumination screened off the test card (R_b), the ratio

$$\frac{R_a - R_b}{R_a}$$

is a measure of the lighting efficiency of the room for the particular scheme of decoration and lighting in use.

Rough measurements can also be made of the transmission, absorption, and reflection factor of various materials.

Table of Daylight Factors
For a Square Aperture of Uniform Brightness

$n = \frac{d}{b}$	▲ %	▲ %	$\frac{▲}{2n▲}$
1·0	11·15	27·7	1·24
1·3	7·06	21·3	1·16
1·5	5·27	17·9	1·13
1·7	4·08	15·1	1·08
2·0	2·81	11·95	1·06
2·5	1·61	8·43	1·04
3·0	0·995	6·18	1·03
3·5	0·660	4·69	1·02
4	0·455	3·68	1·01
5	0·245	2·47	1·00
6	0·140	1·71	,,
7	0·090	1·266	,,
8	·061	0·982	,,
9	·043	0·777	,,
10	·031	0·632	,,

LABORATORY AND WORKSHOP NOTES

SELENIUM CELLS

At the meeting of the Physical Society held on 22nd October Prof. Hans Thirring of Vienna gave a demonstration of his selenium cells, which appear to be of very high sensitivity. Summing up the desirable properties of a light-sensitive cell, he enumerated the following:

(1) Steadiness of resistance; (2) High sensitivity, or ratio of dark to light resistance; (3) Moderate resistance; (4) Linear variation of resistance with illumination; and (5) Small inertia selenium cells were inferior to photo electric cells as regards linear variation and rapidity of response, but greatly superior in constancy and sensitivity to the plane surface type, probably because of the better adhesion of the selenium to the edges of the strips forming the grid; and that small cells were much more sensitive than large ones. For example, a cell having a surface of 10 × 1 mm. gave a current of ·1 μA when dark and 6 μA when illuminated, or a ratio of 60, while a cell of 35 × 7 mm. gave 72 and 439 μA respectively, or a ratio of about 6.

The best method of getting over the inertia of the selenium is to cut the light up into flashes by a revolving sector-disc, amplify the fluctuations, and rectify them by a commutator on the spindle of the disc. By this means, and by focussing the light of a distant small lamp on a cell in a camera, it had been found possible to effect reliable communication over a channel 3 miles wide in broad daylight and to record the passage of ships by the interception of the beam.

MAGNESIUM ALLOYS

ANOTHER advance in light metals has recently been made by the introduction of magnesium in a practically pure state or alloyed with a small proportion of copper. Pure magnesium has a specific gravity of 1·74, or only about two-thirds that of aluminium, and a specific resistance of 4·35 microhms per cm.^{3} at 0° C. so that its weight conductivity is practically the same as that of aluminium. When alloyed with a small proportion of other metals it makes very clean castings which have a tensile strength of 10 tons per square inch and which can be easily turned and screwed without any tendency to tear. Such an alloy has recently been put on the market by Messrs Sterling Metals Ltd. of Coventry under the title "Electron Metal," having a specific gravity of 1·82, and this company are prepared to supply castings of almost any form at about the same cost per piece as aluminium castings. It has already successfully been used, we understand, for engine pistons, crank cases, etc. The material is also available in the form of extrusions, and in this form, the tensile strength may attain 28 tons to the square inch. From a test we have made, the specific resistance of this alloy is about 5·1 microhms per cm.^{3} at about 17° C.

Like aluminium, the alloy cannot be soldered owing to its high affinity for oxygen, and it soon becomes covered with a white film (which the makers state is a protective against further oxidation) in an ordinary atmosphere. In sea water it rapidly corrodes with effervescence, and it is affected by sea air. Thin shavings of it can be ignited like magnesium ribbon, though with some difficulty, but we have been informed that melting it for casting requires great care to avoid ignition. Messrs F. A. Hughes and Co., Ltd., of 204, Great Portland Street, London, W. 1, are the sales agents, and we have just received from them a copy of a provisional specification of the Air Ministry for a modification of the alloy: "Electron metal (Magnesium Casting Alloy AZF)," which is claimed to have improved properties of resistance to sea-water corrosion and to have received exhaustive sea spray tests by the Ministry, with performance equal to Duralumin or L 5 Aluminium. The specific gravity of this alloy is between 1·80 and 1·83, and its chemical composition is as follows: Aluminium 3·5–4·5, Zinc 2·5–3·5, and Manganese 0·7 per cent. with not more than 0·4 Copper, 0·4 Lead, 0·2 Tin, 0·1 Iron, and 0·4 Silicon, the remaining about 90 per cent. being Magnesium. The alloy is specified to have a maximum stress of not less than 12 tons per sq. inch, with an elongation not less than 6 per cent.

HEAT TREATMENT OF METALS

IF sheet zinc, even hard rolled, is heated to about the temperature of boiling water, *i.e.* until drops of water sizzle on it, it may be bent as readily as though it were lead. Its elastic limit is brought down to a low value by the moderate heating.

If a piece of watch spring, or tempered steel wire, be bent between the fingers until one feels it is about to break, and if the part most bent be then held in, say, the flame of a spirit lamp, it will be found that long before temper colours show on the steel, the steel suddenly yields and remains bent. Here, again, the elastic limit of the steel has been brought down to a low value by the moderate heating.

A common practical application of this is in the method of straightening taps and the like which have warped during hardening. These are put under stress to straighten them elastically and then heated up to the point at which they yield. They then retain their straightness after being released, and the heating does not affect the temper of the tools.

It would be of great value in workshops if knowledge were commonly available as to how the plastic properties of various metals are affected by temperature.

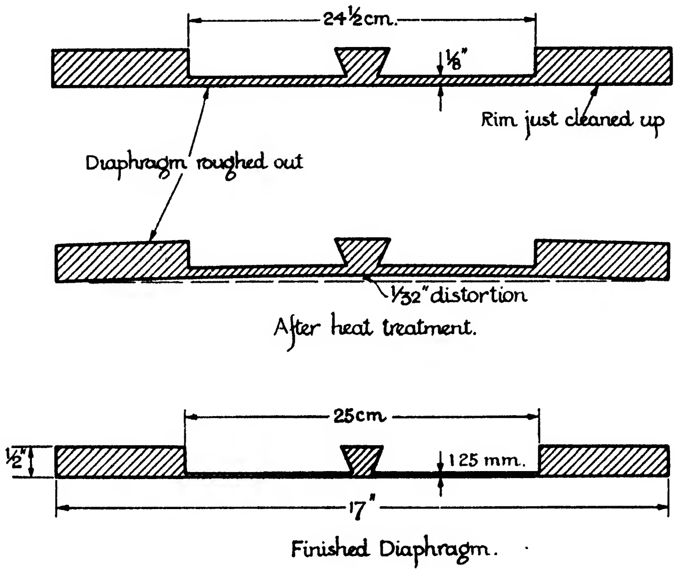
THE TAYLOR-HOBSON LABORATORY, LEICESTER.

DIAPHRAGMS AND HEAT TREATMENT. By F. STOKES.

A steel diaphragm was successfully heat treated and when finished was quite flat and produced a good note. The following method was adopted:

The diaphragm was roughed out all over and then taken out of the lathe.

A steel ring was machined to fit loosely in diaphragm. The diaphragm was next set on a steel disc with a layer of brown paper to allow gradual cooling. The ring was heated up to a dull red, pressed hard into the diaphragm and left to cool. The shrinkage of the centre was sufficient to give a curve of the rim to the extent of 1/32 inches. The diaphragm was then finished, an equal amount of metal being taken off both faces.



An old diaphragm, badly buckled, was reclaimed by this method, except that the ring was not made so hot.

It seems possible that any badly buckled diaphragm can be reclaimed.

The temperature of the ring depends on the thickness of the diaphragm.

A NEW SENSITIVE GALVANOMETER OF SHORT PERIOD AND LOW RESISTANCE

In the *Zeitschrift für Instrumentenkunde* for July, W. J. D. van Dyck of the Physical Institute of Utrecht describes a new form of moving coil galvanometer which fills the gap between the ordinary long period moving coil instruments and the relatively insensitive short period string galvanometers or oscillographs, and at least partially gets over the difficulty of producing a low resistance moving coil galvanometer. The essential feature of the moving system is a short straight silicon bronze wire mounted between two springs and what may be called a half coil, consisting of a single thin copper wire lying close and parallel to this suspension wire and bent over at the two ends so as to be soldered to the middle portion of

the suspension which it shunts. When the current is passed into the suspension through the spring supports, the bulk of it is shunted off into the copper wire owing to its lower resistance, and when the system is between the poles of a magnet a torsion is produced as in an ordinary moving coil. As the arrangement is unsymmetrical, the mirror is mounted on a thin strip of aluminium on the opposite side of the suspension so as to balance it, and one of the magnet poles has a small recess for the mirror to turn in.

The following are the leading particulars of the system:

Suspension. Silicon bronze wire diameter 11μ, length 38 mm.

Half coil. Copper wire, diameter 15μ, length 21 mm., 1·8 mm. from suspension.

Mirror. 1·5 mm. high, 0·8 mm. wide, 0·2 mm. thick.

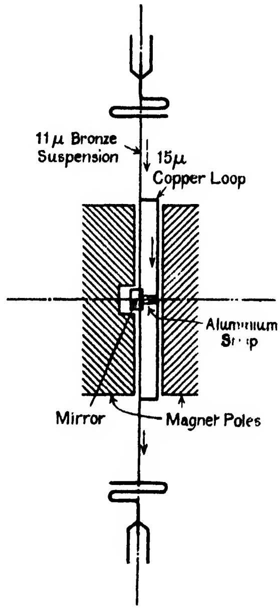
Electromagnet. Resistance 4ω, current 1 to 1·5 amp.

Resistance of moving system. 10ω.

Periodic Time. 0·01 sec.

Sensitivity. 0·3 microampere for 1 mm. at 1 metre.

Messrs Kipp and Zonen of Utrecht are undertaking the construction of this galvanometer under the name Torsion String Galvanometer.



Torsion String Galvanometer

THE PHYSICAL SOCIETY AND THE OPTICAL SOCIETY

SEVENTEENTH ANNUAL EXHIBITION OF ELECTRICAL, OPTICAL AND OTHER PHYSICAL APPARATUS, AT THE IMPERIAL COLLEGE OF SCIENCE AND TECHNOLOGY, TUESDAY, WEDNESDAY AND THURSDAY, JANUARY 4TH, 5TH AND 6TH, 1927.

THE Councils of the above Societies have decided again to include in the Annual Exhibition, in addition to the well-established Trade Section, a Research and Experimental Section similar to that successfully initiated in January, 1926. The groups in this section comprise:

(A) Exhibits illustrating the results of recent physical research and improvements in laboratory practice.

(B) Effective lecture experiments.

(C) Repetitions of famous historical experiments.

Accommodation for these will be provided in rooms distinct from those devoted to the trade exhibits, and a section of the catalogue will be allotted for their description.

No charge will be made for space or catalogue entries in respect of the Research and Experimental Section, and the facilities of the Imperial College will be at the disposal of exhibitors.

The successful development of the Section depends upon the response of Research Laboratories and Institutions and individual research workers to the invitation to exhibit which the Councils of the Societies hereby give.

Offers, giving preliminary particulars of proposed exhibit, including space and other facilities required, should be addressed to the Secretary of the Physical Society at the Imperial College of Science and Technology, South Kensington, S.W. 7, as early as possible, and not later than November 16th.

The Editor of the *Journal* will be obliged if those firms who are exhibiting at the combined Exhibition of the Physical and Optical Societies at South Kensington in January next would kindly let him have brief descriptions, if possible, a fortnight before the Exhibition, of any instruments they will be showing for the first time on this occasion, in order that he may be able to make arrangements for their inspection and for their description in the special number of the *Journal* which will be devoted to the exhibition and be published in January 1927.

The descriptions should be addressed to Dr C. V. Drysdale, *National Physical Laboratory, Teddington, Middlesex.*

JOURNAL OF THE OPTICAL SOCIETY OF AMERICA AND REVIEW OF SCIENTIFIC INSTRUMENTS

The August number of the above journal contains many items of interest. In the scientific section two papers on Colorimetric Purity are contributed by Messrs J. F. Priest and D. B. Judd. Mr F. L. Brown deals with the wave-lengths of the cadmium lines as derived from a vacuum arc or a discharge tube, and concludes that they do not differ by more than 0·001 Ångström unit. An important article on the Validity of Flicker Photometer Measurements in Heterochromatic Photometry is contributed by Mr A. H. Taylor, of the Lighting Research Laboratory of the General Electric Company, Cleveland, who concludes from careful spectrophotometric measurements that even in the case of large colour differences the errors are below 8·5 per cent., and that no other method seems likely to give better results, although there is some indication of systematic error in some cases. He therefore considers that no serious error will result from accepting the results of flicker photometer measurements.

In the Instrument section Messrs A. E. Ruark and M. F. Peters, of the Bureau of Standards, deal with Helmholtz Coils for Producing Uniform Magnetic Fields. The result for the want of uniformity is given by the expression $0{\cdot}144\, r^4/A^4\,(35 \cos 4\theta - 30 \cos 2\theta + 3)$ compared with unity, where r and θ are the polar coordinates of the point considered with respect to the centre and axis of the system, and A is the distance between the mean planes of the coils. An application of this theory is given to the design of a pair of coils to give a field uniform to 1 part in 1000 in a tube 12 cm. long for obtaining the magnetic spectra of photo-electrons. Messrs L. Behr and F. W. Reynolds describe a Free Fall Apparatus in which a ball is released from an electromagnetic and records its motion by sparking through thin paraffin-covered blue paper. A Direct Reading Ionization Gauge is described by C. G. Found and N. B. Reynolds, simplified from that previously devised by Dr Dushman and Mr Found, with a view to easier manufacture. The attention of thermometer makers may be called to the article by Mr B. Noyes, Jr., on Some Defects of Clinical Thermometers, in which the form of the constriction is discussed and its effects on the accuracy and permanence of the indications. Suggestions are also made for a standard method of testing such thermometers, approximating as nearly as possible to their actual use.

In a Note on the Use of the Concave Grating in an Astigmatic Mounting, Mr M. Peterson shows how the difficulty of discriminating between the overlapping spectra of two successive orders can be surmounted without employing an absorbing screen, by the use of a quartz lens, the dispersion of which enables the chosen order to be sharply focused while the

others are diffused. Prof. J. T. Norton of the Massachusetts Institute of Technology describes An X-Ray Spectrograph which contains some interesting mechanical features in the rotating and supporting devices; and Messrs M. Siegbahn and R. Thomas describe A High Vacuum X-Ray Spectrometer enabling wave-lengths up to 12 Ångström units to be employed, or up to 20 A.U. or more with an oxide cathode. Details of the construction and operation of this instrument are given, and specimen spectrograms with wave-lengths of about 8, 16 and 21·5 A.U. The last note, by Messrs A. E. Kumberger and C. E. Lanyon, gives details of A Choke Coil for Controlling Filament Current in X-Ray Tubes, giving a smooth regulation of current from ·5 to 8 amperes at 12 volts, without the contact troubles so frequently manifested in rheostats.

REVIEWS

Aircraft Instruments. By H. N. Eaton and others. Pp. xii + 269. The Ronald Press Co., New York.

Of recent years there has been a growing tendency in scientific literature dealing with specific subjects to appear in the form of "collective works," compiled by groups of several authors, each of whom is a specialist in some branch of the subject. The value of such a practice hardly needs demonstrating; it is surely a sign of the times and an indication of the rapid way in which scientific knowledge is increasing.

The volume under review is the work of seven authors, and though at first sight the subject would appear to be highly special, the very large number and great variety of aeronautical instruments in use is sufficient warrant for a manifold authorship.

Aircraft are free to move in one more dimension than is any other kind of vehicle, and they require, on this account alone, a large number of special instruments. The book deals comprehensively with all of these and includes chapters on such diverse aspects of the subject as instruments for Navigation, for Measurement of Performance, behaviour of Power Plant, and even Oxygen Supply arrangements for high altitude flying. Meteorological instruments, however, are excluded, as are also those used purely for research, which is inferred by the title of the book.

The Authors' object has been to describe instruments in general use, and the principles upon which they operate. The errors to which they are liable are then discussed thoroughly and suggestions for choosing an instrument are made where more than one type is available for a specific duty. Considerations of this kind are also summarised in an appendix, where specifications are given to which newly constructed instruments should conform, and the tests to which they should be subjected are briefly described for the various kinds of instrument.

The book is illustrated by 10 photographic plates and a large number of diagrams and sketches; in view of the nature of the subject, however, still more diagrams would have been advantageous in rendering the descriptions less tedious. In parts of the book some space has been wasted on unnecessary discussion of elementary hydrostatical principles and on the use of consistent units, which might have been more profitably used in amplifying some of the descriptions which in the case of certain instruments shrink to a mere reference to the principles involved. The more important instruments, however, are dealt with at some length, particularly altitude and airspeed indicators.

There is but a slight amount of theory, pure and simple in the book, other than the bare quotation in certain cases of the basic formulae on which the instruments depend.

It is clearly written, easy to read, and, with a few exceptions, the working of the various instruments is readily understood. There is an excellent index, and a plentiful supply of references to other works dealing more fully with particular subjects, a large number of references being made to the publications of the U.S. National Advisory Committee for Aeronautics.

The book should prove of considerable use to those desiring a good knowledge of the capacities and limitations of the instruments they use, or requiring guidance as to the most suitable instrument to select for a particular duty. The Authors are to be congratulated upon the large amount of information they have confined within the limits of a single volume, and the book can be thoroughly recommended.

H. C. H. T.

Photometry. By John W. T. Walsh. Pp. xxvii + 505. (London: Constable and Co., Ltd., 1926.) Price 40*s*. net.

One feels even to-day that in spite of the advances in problems of illumination, too little attention is given to the subject of photometry in schools and colleges; and perhaps short references to the grease spot and shadow photometers dispose of the matter in many cases, while considerations of physical photometers such as the selenium and photo-electric cells are often treated as purely external to the subject. There appears to be a failure to obtain a view of the whole of the subject, to correlate its different parts and to appreciate the contemporary trend of its developments. In this volume, the subject has been ably dealt with from this triple standpoint, and one sees, for example, how closely a knowledge of the eye mechanism and of colour sensation is essential to a correct understanding of the various problems of illumination and photometry. To a thorough understanding of these, this book makes a very real contribution and should undoubtedly be of very great assistance to the research worker and illuminating engineer. At the same time, it is a very valuable review of the many and varied researches on the subject during recent years.

The work deals with visual photometry, with spectrophotometry and with physical photometry. It is evident that the author has had the advantage of close association with the workers and laboratories engaged in the development of each section: and the three sections are well connected in the book. Where the limitations of the book do not permit of a most detailed account being given, there are ample references to the original papers and publications. The preface states that "Where a paper has been reprinted, either in full or lengthy abstract, in journals other than that in which it originally appeared, references to those journals have been placed in the notes after the reference to the original paper." This has the disadvantage of extending the space devoted to the notes, but it is often useful where the only library readily available to the reader is a specialised one, and the number of periodicals accordingly limited. This object has been admirably achieved, and cannot fail to be appreciated by those readers whose reference library facilities are very limited. The bibliography and references are very exhaustive and there should be very little difficulty for any reader who may find portions of the work lacking in detail turning to the necessary paper or book dealing more fully with the particular question.

One is not convinced at this stage that the author has chosen well in preferring wave numbers to wave lengths; fundamentally there are strong reasons for the preference; yet one feels that this point might have been sacrificed for simplicity and the reader left more at ease to grasp the more important features of the book. However, both wave numbers and wave length are generally used and the difficulty should not be a serious one. For similar reasons, one would have liked Chapter II on "Radiation" to have come later had it been possible; the less enthusiastic reader might be deterred from proceeding to the other chapters, which are really the more important from the point of view of photometry. Yet this chapter is an able summary of the present position and ought not to be omitted.

There do not appear to be any serious errors or points for adverse criticism. Possibly the phrase on p. 417 dealing with projected beams stating that "the apparent candle-power in the centre of the beam being often 100 times that near the edge" rather clashes with reference 11 in the same chapter stating "It is common practice in the photometry of projectors to regard as the 'edge' of the beam the line along which the candle-power is equal to one-tenth of the maximum candle-power of the beam." The distinction is one of actual and conventional measurement. Presumably Fig. 67 on p. ix of preface should read Fig. 75.

Undoubtedly the work as a whole can be very highly commended. It is not easy to select any portions for special mention; but the chapters dealing with the Eye and Vision, Spectrophotometry, Measurements of Colour, and Physical Photometry are especially well written. The various instruments used in photometrical and allied work are very satisfactorily described and illustrated. Descriptions of obsolete types have very wisely been confined to the minimum consistent with clarity in stating the principles on which they are based. The 303 drawings and illustrations are well done and are certainly not the least useful part of the book; while the ten appendices, which include standard Symbols, Definitions, energy and luminosity curves and various other factors, will be fully appreciated by all workers in photometry.

S. H.

Commission Internationale de l'Éclairage; Recueil des Travaux et Compte Rendu des Séances. Publié sous la Direction du Bureau Central de la Commission. The National Physical Laboratory, Teddington, Angleterre. (Cambridge University Press, 1926; pp. 432; 15*s*. net.)

It is significant of the growing status and importance of the science and art of illumination that the proceedings of the International Commission of Illumination which met in Geneva in July, 1924, should result in the production of such an imposing volume.

The first eighty pages are taken up with the official account of the meetings, in French, together with a record of the decisions taken by the Commission. One of the decisions most important from a purely scientific point of view is the one to the effect that the adoption of the black body radiator be recommended as a primary standard of light and that the national laboratories be asked to commence work which, it is hoped, will result in agreement being obtained in the next few years on the value to be assigned to the brightness of the black body under definite reproducible conditions. Of interest in another direction is the one which urges all national committees to concentrate on the study of street lighting and motor car headlight problems to which it is intended serious consideration should be given at the next meeting of the Commission.

After this are given in full the twenty-nine papers presented to the Commission by American, British, French and Italian scientists and engineers. Papers are included by members of the national laboratories of the first three countries. It is impossible to deal with the subject-matter of any of these papers in detail. Suffice it to say that they cover a very large field of important problems in illumination dealing with the scientific, technical, hygienic, commercial and standardisation aspects of the subject. What appears to be a useful innovation in publications of this description is that each paper is preceded by a summary in two other languages than that of the original paper.

Three papers are interesting as being outside what is usually considered to be the purview of a purely technical body. These are the papers dealing with the possibilities of co-operation of the central stations and manufacturers' associations in carrying out educational and propaganda work in favour of scientific and hygienic lighting, and they illustrate how the American public is being interested in the problems of illumination.

The work will be of great interest to all those who are engaged in the study or business of illumination as well as those interested in the social and industrial well-being of the community so far as it is influenced by lighting conditions.

The editing and printing leave nothing to be desired, and credit is due to the responsible persons.

H. B.

Photographic Photometry. A Study of Methods of Measuring Radiation by Photographic Means. By G. M. B. Dobson, D.Sc., I. O. Griffiths, M.A. and D. N. Harrison, D.Phil. Pp. 121. (Oxford: at the Clarendon Press, 1926.) Price 7*s*. 6*d*. net.

In spite of the obvious theoretical simplicity of the methods of photographic photometry, the results of such methods in actual practice have usually been disappointing, and it is probably correct to state that, apart from isolated examples, the majority of the results obtained until very recently have been subject to relatively large and uncertain errors. As the authors state, the ordinarily used methods cannot be relied upon to give a greater accuracy than 5 to 10 per cent. probable error. This means that, without apparent reason, errors as large as 10 to 20 per cent., if not more, are easily possible unless the proper precautions are taken.

It is to the credit of the authors that, as a result of several years' experience, they have succeeded in determining what the proper precautions are, so that the photographic plate may be used as a scientific instrument of quite reasonable precision.

In photographic photometry there are two main problems before the investigator. The first is that of the actual production of a photographic plate from which the required information can be deduced, and the second is that of measuring the density of the photographic image (often a very small area of it) with some kind of photometer. Both problems present many difficulties, but it is with the first that the authors are mainly concerned.

The first chapter deals with the general characteristics of the photographic plate. One could have wished for a little fuller treatment here, as it assumes rather more knowledge on the part of the reader than is implied by the authors' remark that it is intended for workers using this method for the first time. The distinction between "intensity" and "amount of light" is not made clear on pp. 21 and 22, while i is the logarithm of the inertia and not the inertia itself as is implied on p. 22. It is usual, however, to write the Hurter and Driffield equation in the form $D = \gamma\,(\log It^p - \log i)$, where i is the inertia.

The second chapter describes the various methods of working and gives the theory of the methods which the authors have found suitable for different types of problem. The treatment is complete but rather difficult to read, as it is expressed with almost mathematical brevity.

The next chapter gives a rather short description of the instruments for measuring photographic density.

Chapters four and five, giving the theoretical best conditions of working and the errors and precautions, are the best in the book. The variation in effective aperture at different points of the plate in a spectrograph is mentioned briefly. The importance of this effect and the frequency with which it often occurs in ordinary spectrographs would seem to warrant greater attention to this point.

Chapter six deals with plates and developers.

Chapter seven gives examples of the application of the methods used by the authors to three problems, viz. the temperature of the carbon arc under pressure, the change in ultra-violet light brightness across the sun's disc and the amount of ozone in the atmosphere.

The book should be exceedingly useful to all those who are using or contemplating the quantitative use of the photographic method.

H. B'

PROCEEDINGS OF THE OPTICAL CONVENTION 1926

It is now announced that the Proceedings of the Optical Convention will be ready in the first week of December.

The book is in two cloth bound and fully illustrated quarto volumes, each of over 500 pages and contains the Presidential Address and the papers read at the Convention, with a full report of the discussions thereon. Owing to its large size and heavy cost it has been necessary to increase the price from the sum originally announced to £3 for the complete work. Orders at the rate of £3. 1*s*. 3*d*. including postage should be addressed to The Secretary, The Optical Convention 1926, 1, Lowther Gardens, Exhibition Road, London, S.W. 7.

TABULAR INFORMATION ON SCIENTIFIC INSTRUMENTS

XIV. BRITISH OPTICAL GLASSES

Great advances have been made in the production of Optical Glass in Great Britain during and since the War by Messrs. Chance Bros., Messrs. Barr and Stroud, and Messrs. Parsons, and it is thought that a complete table of these glasses would be of value to Optical Designers. Messrs. Barr and Stroud only manufacture glass for their own use, but the following tables have been compiled from the lists issued by Messrs. Chance and Messrs. Parsons. They are not strictly comparable, as Messrs. Parsons give refractive indices and dispersions for six lines which are not coincident with those of Messrs. Chance, but the figures are reproduced for three lines which correspond fairly closely.

Separate copies of this list can be obtained by any reader on application to the Secretary of the Institute of Physics, 90, Great Russell Street, W.C. 1, and a set of all the tables in the current volume will be obtainable at a nominal price when it is completed.

XIV. BRITISH OPTICAL GLASSES

Maker:—Messrs Chance Bros. & Co., Ltd., Glass Works, Smethwick, Birmingham.

Wave lengths: C = 6563, D = 5893, F = 4861, G' = 4340.

Type No.	Variety of glass	n_D	Mean dispersion C—F	ν	Partial dispersions C—D	Partial dispersions D—F	Partial dispersions F—G'	Relative partial dispersions C—D	Relative partial dispersions D—F	Relative partial dispersions F—G'	Specific gravity	Durability	Remarks	List price per lb. s. d.
7714	Fluor crown	1·4811	·00685	70·3	·00205	·00480	·00382	·300	·700	·557	2·45	1	—	40 0
7423	Fluor crown	1·4785	·00682	70·2	·00202	·00480	·00363	·296	·704	·532	2·47	1	—	40 0
3484	Boro-silicate crown	1·4980	·00763	65·3	·00227	·00536	·00425	·298	·702	·557	2·40	1	—	12 6
646	Boro-silicate crown	1·5087	·00793	64·1	·00237	·00556	·00445	·299	·701	·561	2·46	1	—	12 6
6493	Boro-silicate crown	1·5160	·00809	63·8	·00242	·00567	·00454	·299	·701	·561	2·54	1	—	12 6
7742	Boro-silicate crown	1·5194	·00825	63·0	·00247	·00578	·00465	·299	·701	·564	2·56	2	—	12 6
1061	Boro-silicate crown	1·5126	·00818	62·7	·00245	·00573	·00460	·300	·700	·562	2·52	2	—	12 6
4990	Boro-silicate crown	1·5100	·00821	62·1	·00246	·00575	·00462	·299	·701	·562	2·50	2	—	12 6
9753	Dense barium crown	1·5881	·00962	61·1	·00287	·00675	·00541	·298	·702	·563	3·31	2–3	T	19 0
1203	Hard crown	1·5155	·00848	60·8	·00250	·00598	·00482	·295	·705	·568	2·48	1–2	—	9 6
605	Hard crown	1·5175	·00856	60·5	·00254	·00602	·00484	·297	·703	·565	2·49	1–2	—	9 6
9322	Hard crown	1·5186	·00860	60·3	·00254	·00606	·00489	·295	·705	·569	2·49	2	—	9 6
2265	Dense barium crown	1·6016	·00999	60·2	·00296	·00703	·00565	·296	·704	·565	3·46	2–3	—	19 0
3820	Telescope crown	1·5153	·00858	60·0	·00254	·00604	·00485	·296	·704	·565	2·50	2	—	9 6
9663	Hard crown	1·5204	·00869	59·9	·00257	·00612	·00492	·296	·704	·566	2·58	2	—	9 6
8065	Dense barium crown	1·6130	·01025	59·8	·00302	·00723	·00582	·294	·706	·568	3·58	2	—	19 0
4317	Dense barium crown	1·6051	·01014	59·7	·00300	·00714	·00576	·296	·704	·568	3·44	2–3	T	19 0
3465	Dense barium crown	1·6160	·01035	59·5	·00305	·00730	·00588	·294	·706	·568	3·60	2	—	19 0
3463	Light barium crown	1·5407	·00910	59·4	·00268	·00642	·00517	·295	·705	·568	2·90	1	—	9 6
5618	Medium barium crown	1·5761	·00970	59·4	·00284	·00686	·00551	·293	·707	·568	3·25	2	—	16 6
3071	Hard crown	1·5215	·00878	59·4	·00261	·00617	·00497	·297	·703	·566	2·48	2	—	9 6
9071	Hard crown	1·5193	·00877	59·2	·00261	·00616	·00497	·298	·702	·567	2·55	2	—	9 6
4873	Dense barium crown	1·6118	·01037	59·0	·00305	·00732	·00590	·294	·706	·569	3·56	2	T	19 0
3055	Dense barium crown	1·5938	·01006	59·0	·00298	·00708	·00571	·296	·704	·568	3·47	2	T	19 0
4283	Dense barium crown	1·5995	·01017	58·9	·00300	·00717	·00578	·295	·705	·568	3·50	2	T	19 0
5663	Dense barium crown	1·5981	·01019	58·7	·00300	·00719	·00579	·294	·706	·568	3·49	2	T	19 0
1565	Dense barium crown	1·6105	·01046	58·4	·00307	·00739	·00595	·293	·707	·569	3·55	2	—	19 0
580	Dense barium crown	1·6065	·01046	58·0	·00308	·00738	·00596	·294	·706	·570	3·52	2	T	19 0
1066	Zinc crown	1·5149	·00890	57·9	·00265	·00625	·00506	·298	·702	·569	2·62	1	—	9 6
5481	Medium barium crown	1·5708	·00986	57·9	·00290	·00696	·00561	·294	·706	·569	3·19	1–2	—	14 0
9002	Medium barium crown	1·5744	·00995	57·7	·00292	·00703	·00567	·293	·707	·570	3·23	1–2	—	14 0
2665	Dense barium crown	1·6089	·01061	57·4	·00312	·00749	·00606	·294	·706	·572	3·53	2	—	17 0
569	Soft crown	1·5152	·00906	56·9	·00265	·00641	·00517	·292	·708	·571	2·55	3–4	—	9 6
8793	Dense barium crown	1·6140	·01080	56·9	·00316	·00764	·00618	·293	·707	·572	3·60	2	T	17 0
1163	Dense barium crown	1·6114	·01077	56·8	·00315	·00762	·00616	·292	·708	·572	3·58	2	T	17 0
6165	Dense barium crown	1·6210	·01092	56·8	·00320	·00772	·00627	·293	·707	·575	3·64	2	—	17 0
1453	Dense barium crown	1·6126	·01080	56·7	·00316	·00764	·00617	·293	·707	·571	3·56	2	T	17 0
3572	Dense barium crown	1·6151	·01089	56·5	·00319	·00770	·00625	·293	·707	·574	3·61	2	T	17 0
842	Dense barium crown	1·6066	·01076	56·4	·00314	·00762	·00616	·292	·708	·572	3·53	2	T	17 0
2065	Dense barium crown	1·6134	·01090	56·3	·00319	·00771	·00626	·292	·708	·575	3·58	2	—	17 0
563	Medium barium crown	1·5660	·01006	56·3	·00295	·00711	·00574	·293	·707	·571	3·09	2	—	14 0
6665	Dense barium crown	1·6234	·01107	56·3	·00323	·00784	·00636	·291	·709	·575	3·66	2	—	17 0
5542	Dense barium crown	1·6084	·01085	56·1	·00318	·00767	·00621	·293	·707	·572	3·53	2	T	17 0
3265	Dense barium crown	1·6150	·01097	56·1	·00323	·00776	·00630	·292	·708	·575	3·58	2	—	17 0
7472	Medium barium crown	1·5837	·01041	56·1	·00304	·00737	·00596	·292	·708	·573	3·29	1–2	—	14 0
1065	Dense barium crown	1·6065	·01090	55·6	·00319	·00771	·00626	·293	·707	·575	3·54	2	T	17 0
4469	Light barium flint	1·5661	·01029	55·0	·00301	·00728	·00591	·293	·707	·574	3·14	1–2	—	9 6
535	Light barium flint	1·5452	·01020	53·5	·00298	·00722	·00582	·292	·708	·571	2·98	1–2	—	9 6
8894	Dense barium crown	1·6100	·01145	53·3	·00333	·00812	·00663	·291	·709	·579	3·53	1–2	—	17 0
4277	Telescope flint	1·5237	·01003	52·2	·00295	·00708	·00577	·294	·706	·575	2·67	2	Y*	12 6
3084	Light barium flint	1·5724	·01096	52·2	·00320	·00776	·00636	·291	·709	·583	3·16	2	—	9 6
5062	Light barium flint	1·5515	·01067	51·7	·00310	·00756	·00619	·291	·709	·581	2·99	2	—	9 6
7863	Extra light flint	1·5290	·01026	51·6	·00300	·00726	·00593	·292	·708	·578	2·56	1	—	7 0
1078	Light barium flint	1·5523	·01075	51·4	·00313	·00762	·00624	·291	·709	·581	3·06	2	—	9 6
3390	Extra light barium flint	1·5372	·01075	50·0	·00312	·00764	·00626	·290	·710	·582	2·85	2	—	9 6
485	Extra light flint	1·5333	·01099	48·5	·00320	·00779	·00640	·291	·709	·582	2·80	3	—	7 0
4075	Light flint	1·5427	·01142	47·5	·00331	·00881	·00672	·290	·710	·588	2·90	2	—	7 0
4628	Medium barium flint	1·5832	·01242	47·0	·00362	·00880	·00732	·291	·709	·589	3·28	2	—	9 6
466	Light barium flint	1·5833	·01251	46·6	·00362	·00889	·00738	·289	·711	·590	3·30	2	—	9 6
7983	Light barium flint	1·5534	·01201	46·1	·00347	·00854	·00711	·289	·711	·592	2·96	2	—	9 6
458	Light flint	1·5472	·01196	45·8	·00348	·00848	·00707	·291	·709	·591	2·93	1–2	—	7 0
1018	Light flint	1·5491	·01206	45·5	·00348	·00858	·00714	·289	·711	·592	2·95	1–2	—	7 0
1033	Light barium flint	1·5734	·01299	44·1	·00374	·00925	·00769	·288	·712	·592	3·16	1–2	—	9 6
665	Light barium flint	1·5677	·01291	44·0	·00371	·00920	·00763	·288	·712	·591	3·08	1–2	—	9 6
4153	Dense barium flint	1·6055	·01387	43·6	·00400	·00987	·00821	·288	·712	·592	3·48	2	—*	13 0
4159	Light barium flint	1·5766	·01334	43·2	·00384	·00950	·00795	·288	·712	·596	3·18	1	—	9 6
8653	Light flint	1·5632	·01312	42·9	·00375	·00937	·00781	·286	·714	·595	3·07	1	—	7 0
1017	Light flint	1·5746	·01388	41·4	·00396	·00992	·00830	·285	·715	·598	3·18	1	—	7 0
410	Light flint	1·5760	·01404	41·0	·00402	·01002	·00840	·286	·714	·598	3·20	1	—	7 0
407	Light flint	1·5787	·01420	40·8	·00406	·01014	·00851	·286	·714	·599	3·26	1–2	—	7 0
4626	Dense barium flint	1·6236	·01582	39·4	·00453	·01129	·00957	·286	·714	·605	3·66	2	—	13 0
5953	Dense barium flint	1·6059	·01593	38·0	·00453	·01140	·00967	·284	·716	·605	3·49	2	—	13 0
1034	Dense flint	1·6041	·01599	37·8	·00457	·01142	·00969	·286	·714	·606	3·47	1	—	7 6
1068	Dense flint	1·6089	·01632	37·3	·00465	·01167	·00989	·285	·715	·606	3·52	1	—	7 6
3743	Dense flint	1·6125	·01655	37·0	·00471	·01184	·01003	·285	·715	·606	3·54	1	—	7 6
4743	Dense flint	1·6134	·01662	36·9	·00473	·01189	·01008	·285	·715	·606	3·55	1	—	7 6
370	Dense flint	1·6118	·01657	36·9	·00472	·01185	·01005	·285	·715	·607	3·54	1	—	7 6
572	Dense flint	1·6182	·01697	36·4	·00484	·01213	·01031	·285	·715	·608	3·60	1	—	7 6
361	Dense flint	1·6214	·01722	36·1	·00491	·01231	·01047	·285	·715	·608	3·63	1	—	7 6
360	Dense flint	1·6225	·01729	36·0	·00492	·01237	·01052	·285	·715	·608	3·64	1–2	—	7 6
4675	Very dense barium flint	1·6683	·01876	35·6	·00533	·01343	·01147	·284	·716	·611	3·98	2	YT	13 0
337	Very dense flint	1·6469	·01917	33·7	·00541	·01376	·01170	·282	·718	·610	3·87	2	T	10 6
5093	Very dense flint	1·6501	·01936	33·6	·00544	·01392	·01190	·281	·719	·615	3·90	2	T	10 6
3994	Very dense flint	1·6715	·02076	32·3	·00589	·01487	·01285	·284	·716	·619	4·08	2	—	15 0
4141	Very dense flint	1·7167	·02430	29·5	·00686	·01744	·01511	·282	·718	·622	4·47	2–3	YT	30 0
4488	Very dense flint	1·7402	·02608	28·4	·00731	·01877	·01642	·280	·720	·630	4·67	2–3	YT	30 0
7972	Very dense flint	1·7566	·02754	27·5	·00774	·01980	·01736	·281	·719	·630	4·82	2–3	*YT	30 0

T, Tarnishes slightly. Y, Slight yellow tinge. * For reduction of secondary spectrum.

Maker:—PARSONS OPTICAL GLASS Co., LITTLE CHESTER, DERBY.

Wave lengths: b = 7065, C = 6563, d = 5875, e = 5461, F = 4861, g = 4359, h = 4047, D = 5893, G^1 = 4341.

Type	No.	Variety of glass	Refractive index for d line n_d	Mean dispersion C—F	$\frac{n_d-1}{n_F-n_C}$ v	Partial dispersions C—d	d—F	F—g	Relative partial dispersions $\frac{C-d}{C-F}$	$\frac{d-F}{C-F}$	$\frac{F-g}{C-F}$	Specific gravity	LIST PRICE per lb. *s. d.*
FC	1	Fluor crown	1·49429	·00728	67·9	·00226	·00503	·00388	·310	·690	·532	2·41	30 0
BSC	1	Borosilicate crown	1·50618	·00775	65·3	·00239	·00536	·00415	·308	·692	·535	2·42	9 0
BSC	2	,, ,,	1·51094	·00805	63·5	·00248	·00557	·00435	·308	·692	·540	2·48	9 0
BSC	3	,, ,,	1·50768	·00802	63·3	·00246	·00556	·00431	·307	·693	·537	2·47	9 0
BSC	4	,, ,,	1·51830	·00824	62·9	·00253	·00571	·00443	·307	·693	·538	2·50	9 0
BSC	5	,, ,,	1·51269	·00815	62·9	·00250	·00565	·00438	·307	·693	·537	2·48	9 0
BSC	6	,, ,,	1·50466	·00812	62·1	·00248	·00564	·00438	·305	·695	·539	2·45	9 0
BSC	7	,, ,,	1·51510	·00802	64·2	·00246	·00556	·00433	·307	·693	·540	2·49	9 0
HC	1	Hard crown	1·51607	·00849	60·8	·00257	·00592	·00461	·303	·697	·543	2·50	7 9
HC	2	,, ,,	1·51654	·00855	60·4	·00262	·00593	·00464	·306	·694	·543	2·49	7 9
HC	3	,, ,,	1·52339	·00870	60·2	·00265	·00605	·00472	·305	·695	·543	2·52	7 9
HC	4	,, ,,	1·51764	·00878	59·0	·00267	·00611	·00479	·304	·696	·546	2·52	7 9
HC	5	,, ,,	1·51944	·00860	60·4	·00263	·00597	·00467	·306	·694	·543	2·60	10 0
LBC	1	Light barium crown	1·54008	·00905	59·7	·00276	·00629	·00493	·305	·695	·545	2·87	12 6
ZC	1	Zinc crown	1·53587	·00923	58·1	·00280	·00643	·00505	·303	·697	·547	2·72	9 6
MBC	1	Medium barium crown	1·57220	·00991	57·7	·00299	·00691	·00543	·302	·698	·548	3·19	15 0
MBC	2	,, ,, ,,	1·57644	·01003	57·5	·00301	·00702	·00550	·300	·700	·548	3·23	15 0
MBC	3	,, ,, ,,	1·56026	·00999	56·1	·00302	·00697	·00551	·302	·698	·552	3·09	9 6
MBC	4	,, ,, ,,	1·56431	·01013	55·7	·00306	·00707	·00558	·302	·698	·551	3·10	9 6
MBC	5	,, ,, ,,	1·56527	·01023	55·3	·00309	·00714	·00565	·302	·698	·552	3·10	9 6
DBC	1	Dense barium crown	1·59644	·01000	59·6	·00304	·00696	·00543	·304	·696	·543	3·37	19 0
DBC	2	,, ,, ,,	1·61093	·01027	59·5	·00312	·00715	·00559	·304	·696	·544	3·54	19 0
DBC	3	,, ,, ,,	1·61342	·01035	59·3	·00316	·00719	·00563	·305	·695	·544	3·56	19 0
DBC	4	,, ,, ,,	1·61239	·01046	58·5	·00318	·00728	·00571	·304	·696	·546	3·55	19 0
DBC	5	,, ,, ,,	1·60485	·01040	58·2	·00316	·00724	·00568	·304	·696	·546	3·46	19 0
DBC	6	,, ,, ,,	1·61217	·01051	58·2	·00320	·00731	·00574	·304	·696	·546	3·56	19 0
DBC	7	,, ,, ,,	1·61334	·01065	57·6	·00323	·00742	·00583	·303	·697	·547	3·57	16 9
DBC	8	,, ,, ,,	1·61029	·01066	57·3	·00323	·00743	·00584	·303	·697	·548	3·53	14 0
DBC	9	,, ,, ,,	1·62090	·01086	57·2	·00328	·00758	·00595	·302	·698	·548	3·65	16 9
DBC	10	,, ,, ,,	1·61321	·01080	56·8	·00327	·00753	·00593	·303	·697	·549	3·59	16 9
DBC	11	,, ,, ,,	1·60957	·01075	56·7	·00326	·00749	·00590	·303	·697	·549	3·56	16 9
DBC	12	,, ,, ,,	1·61803	·01095	56·4	·00331	·00764	·00601	·302	·698	·549	3·62	16 9
DBC	13	,, ,, ,,	1·61339	·01100	55·8	·00332	·00768	·00606	·302	·698	·551	3·61	16 9
DBC	14	,, ,, ,,	1·61815	·01110	55·7	·00335	·00775	·00613	·302	·698	·552	3·65	16 9
DBC	15	,, ,, ,,	1·61582	·01116	55·2	·00336	·00779	·00616	·301	·699	·552	3·64	16 9
DBC	16	,, ,, ,,	1·60828	·01121	54·3	·00338	·00783	·00621	·302	·698	·554	3·56	16 9
DBC	17	,, ,, ,,	1·61074	·01140	53·6	·00342	·00798	·00633	·300	·700	·555	3·59	16 9
SC	1	Soft crown	1·52772	·01011	52·2	·00306	·00705	·00561	·303	·697	·555	2·72	7 0
SC	2	,, ,,	1·52980	·01029	51·5	·00310	·00719	·00572	·301	·699	·556	2·74	7 0
SC	3	,, ,,	1·52069	·01013	51·4	·00306	·00707	·00565	·302	·698	·558	2·69	7 0
TF	1	Telescope flint	1·51516	·00904	57·0	·00274	·00630	·00496	·303	·697	·549	2·58	12 6
TF	2	,, ,,	1·51507	·00914	56·4	·00278	·00636	·00500	·304	·696	·547	2·59	12 6
TF	3	,, ,,	1·53042	·01021	52·0	·00310	·00711	·00561	·304	·696	·549	2·58	17 6
BLF	1	Barium light flint	1·57897	·01070	54·1	·00322	·00748	·00590	·301	·699	·551	3·22	9 6
BLF	2	,, ,, ,,	1·54856	·01024	53·6	·00308	·00716	·00567	·301	·699	·554	2·96	9 6
BLF	3	,, ,, ,,	1·58070	·01083	53·6	·00326	·00757	·00599	·301	·699	·553	3·24	9 6
BLF	4	,, ,, ,,	1·54925	·01049	52·4	·00315	·00734	·00583	·300	·700	·556	2·97	9 6
ELF	1	Extra light flint	1·55164	·01207	45·7	·00360	·00847	·00687	·298	·702	·569	2·98	6 0
ELF	2	,, ,, ,,	1·54886	·01211	45·3	·00361	·00850	·00686	·298	·702	·566	2·97	6 0
ELF	3	,, ,, ,,	1·54856	·01177	46·6	·00353	·00824	·00664	·300	·700	·564	2·95	6 0
BF	1	Barium flint	1·58057	·01268	45·8	·00376	·00891	·00720	·297	·703	·568	3·24	9 6
BF	2	,, ,,	1·60483	·01380	43·8	·00410	·00970	·00787	·297	·703	·570	3·47	9 6
BF	3	,, ,,	1·60833	·01537	39·6	·00453	·01084	·00889	·295	·705	·578	3·49	10 0
BF	4	,, ,,	1·62274	·01574	39·6	·00464	·01110	·00910	·295	·705	·578	3·63	10 0
LF	1	Light flint	1·56745	·01295	43·8	·00386	·00909	·00739	·298	·702	·571	3·10	5 6
LF	2	,, ,,	1·56390	·01310	43·0	·00388	·00922	·00746	·296	·704	·569	3·10	5 6
LF	3	,, ,,	1·57453	·01348	42·6	·00401	·00947	·00770	·297	·703	·571	3·18	5 6
LF	4	,, ,,	1·58251	·01392	41·8	·00413	·00979	·00796	·297	·703	·572	3·24	5 6
LF	5	,, ,,	1·57591	·01395	41·3	·00413	·00982	·00798	·296	·704	·572	3·22	5 6
DF	1	Dense flint	1·60545	·01592	38·0	·00470	·01122	·00924	·295	·705	·580	3·50	5 6
DF	2	,, ,,	1·61323	·01661	36·9	·00489	·01172	·00967	·294	·706	·582	3·55	5 6
DF	3	,, ,,	1·61768	·01690	36·5	·00497	·01193	·00984	·294	·706	·582	3·60	5 6
DF	4	,, ,,	1·62308	·01729	36·0	·00509	·01220	·01009	·294	·706	·583	3·65	5 6
EDF	1	Extra dense flint	1·65035	·01929	33·7	·00563	·01366	·01137	·292	·708	·589	3·89	7 6
EDF	2	,, ,, ,,	1·65336	·01946	33·6	·00569	·01377	·01147	·292	·708	·589	3·92	7 6
DEDF	1	Double extra dense flint	1·74135	·02681	27·7	·00775	·01906	·01617	·289	·711	·603	4·63	18 0
DEDF	2	,, ,, ,, ,,	1·76724	·02888	26·6	·00831	·02057	·01752	·288	·712	·607	4·84	18 0
DEDF	3	,, ,, ,, ,,	1·74723	·02724	27·4	·00785	·01939	·01642	·288	·712	·603	4·68	18 0

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SMALL STANDARD VARIABLE AIR CONDENSERS OF LOW MINIMA.

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ABSTRACT. Two types of shielded variable air condensers have been investigated in order to determine which would give: (1) the smallest absolute minimum capacity with a variation of about 20 $\mu\mu$ F.; (2) the largest ratio of maximum to minimum capacity, with a variation of about 60 $\mu\mu$ F.

The best values actually obtained for the minima in these two cases were 3·5 $\mu\mu$ F. and 5·3 $\mu\mu$ F. respectively.

It was found that flat semicircular plates were superior to cylindrical segmental ones. The lowest minimum was obtained when the moving system was insulated on the underside of the top bearing.

Disconnexion and earth-capacity errors have been fully determined, and these indicate that the absolute values of capacity can be relied upon to less than 0·2 $\mu\mu$ F.

INTRODUCTION

UNLIKE an adjustable mutual inductance, a variable air condenser cannot be decreased to zero, and, in consequence, often complete disconnexion from the circuit has to be made. This is undesirable from many points of view, especially in quantitative work at very high radio-frequencies, where the total capacity in the circuit is generally less than one hundred micromicrofarads.

The minimum value of a condenser is of considerable consequence in some cases. For instance, in determinations of the self-capacities of coils it is desirable to have one or two points as low down on the scale as possible to reduce errors of extrapolation.

Hartshorn* has shown that complete screening is essential in order that the effective capacity between terminals may be independent of position and potential, and this is attained by connecting the screen to one of the plate systems. Unshielded instruments, especially of low range, are useless for making accurate measurements, as the effective capacity between the plates is then a function of the potential distribution of the circuit and the values of the earth-capacities of the two systems: the capacity thus being by no means constant for a given setting. Only carefully shielded instruments are considered here. The only disadvantage of complete screening is the unavoidable increase produced in the minimum value of the capacity when one system is swung clear of the other.

Low minima depend upon the effectiveness of the reduction of capacity between the two sets of plates and between the insulated system and the screen.

Small bulk is also a good feature, especially in those of the "vernier" type, which are usually connected in parallel with a standard of greater range.

* *Journ. Scient. Instr.* 1, No. 10, July, 1924.

General Design

The size of plates for a given air-gap and variation of capacity C can be calculated to a few per cent. from the well-known formula

$$C = \frac{KA}{3{\cdot}6\pi d},$$

where C = capacity variation in $\mu\mu$ F.,
A = total area in sq. cms.,
d = air-gap in cms.,
K = dielectric constant (air = 1).

An air-gap of 1 mm. was adopted throughout as standard, being about the smallest that could be adopted without endangering constancy of calibration due to such causes as slight plate sag with time.

In the early stages of making the measurements it was clearly seen that the stray effects, which are not readily calculable, were in some cases very much larger than even rough estimates would indicate, so that the general procedure was one of trial and error until the desired result was obtained.

Two general types have been investigated with various modifications to ascertain which was more desirable. The criteria in general have been the values of minimum capacity and the ratio of maximum to minimum, together with ease of construction and mechanical robustness.

The types were condensers with:

(1) cylindrical segmental plates;

(2) flat semicircular plates,

in which either the fixed or moving systems were insulated.

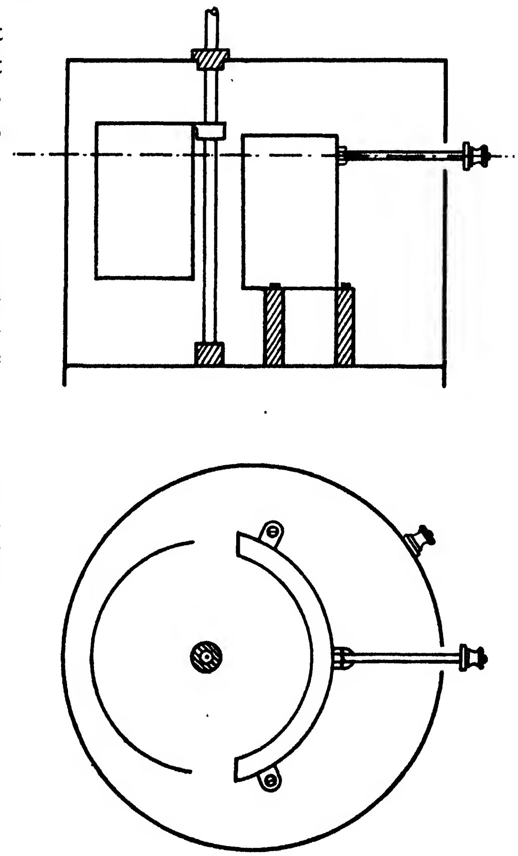

Fig. 1

Type (1). *Cylindrical segmental plates*

It was thought at first that most of the capacity in the ordinary variable condenser was between the central boss and the edges of the other bank of plates.

This led to the adoption of the scheme shown in Fig. 1. The insulated system was fixed and supported on three small ebonite pillars about 2 cm. high, and was mounted practically centrally in its screen so that the screen capacity would be as small as possible. This involved the spindle of the moving plates being mounted eccentrically which, for a given size of screen, enabled the capacity between the insulated system and the screen to be reduced considerably.

In this particular instrument "*A*," the moving vane was also insulated, and in consequence a separation of the mutual capacities could be effected. Particulars of condenser "*A*" are given in Tables I and II while the notation adopted is made clear from Fig. 2.

Table I. *Principal Dimensions of Condenser "A"*

Plates: 1 moving, 2 fixed. Air-gap: 1 mm.
Mean radius: 3 cm. Mean height: 4 cm.
Edge to edge clearance, minimum position: 1 cm.
Height of screen: 8 cm. Radius of screen: 5 cm.
Height of insulating pillars: 2 cm.

Table II

Setting	(*a*)	(*b*)	(*c*)	Moving to screen = (*a* + *c*)	Ratio: max./min.
Minimum	1.8 $\mu\mu$ F.	10.0 $\mu\mu$ F.	6.2 $\mu\mu$ F.	{ 8.0 $\mu\mu$ F. { 7.8 (measured) $\mu\mu$ F.	
Maximum	—	—	—	68.6 $\mu\mu$ F.	

The high value of "*b*" is due to the fact that the moving vane swings out very near to the shield owing to the eccentric mounting. It is however immaterial as that capacity is normally shortcircuited.

One interesting point, however, is the surprisingly small value of the edge capacity which forms the greater part of "*a*."

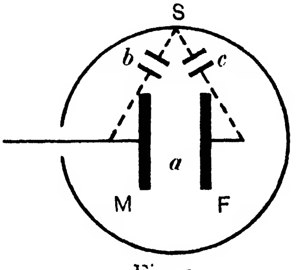

Fig. 2

The next modification consisted in screwing the fixed plates directly on to the inside of the screen and insulating the moving vane.

Condensers built on this system are not uncommon but it is usual practice to support the moving plates from the top bearing, which is carried by an insulating washer let into the screen. The washer is generally of amber or amberite, but this substance is not very good with respect to dielectric losses at radio-frequencies. The disadvantages of insulated bearings may be briefly summarised thus:

(1) Less perfect screening.

(2) Large insulation capacity, which is undesirable from the point of view of both minimum value and dielectric losses.

To ascertain the effect on the minimum, measurements were made with the spindle alone in the shield. It consisted of a brass rod only $\frac{1}{8}$ in. diameter, carried at the lower end by an ebonite footstep bearing, and insulated at the top by a small ebonite bush. The results are given in Table III.

Table III

	Capacity
Bottom footstep bearing	0.4 $\mu\mu$ F.
Spindle between top and bottom of screen	0.9 $\mu\mu$ F.
Top bearing	2.4 $\mu\mu$ F.
Total	3.7 $\mu\mu$ F

It therefore became quite evident that, if minima of less than 5 $\mu\mu$ F. were to be obtained, insulated bearings would have to be discarded.

The design shown in Fig. 3 was then developed and found satisfactory: condenser "*B*" differing from the drawing in that it had cylindrical plates. It was calculated to give 20 $\mu\mu$ F. total variation. The particulars are given in Tables IV and V.

Table IV. *Principal Dimensions of Condenser "B"*

Plates: 1 moving and insulated, 2 fixed. Air-gap: 1 mm.
Mean radius: 3 cm. Mean height: 2 cm.
Edge to edge clearance, minimum position: 3·5 cm.
Height of screen: 8 cm. Radius of screen: 5 cm.

Table V

Setting	Capacity	Ratio: max./min.
Minimum	4·0 $\mu\mu$ F.	6
Maximum	23·5 $\mu\mu$ F.	

It was found that the edge clearance was excessive and some observations indicated that one of this type could be designed ranging from about 4·6 $\mu\mu$ F. to 30 $\mu\mu$ F., giving a max./min. ratio of about 6·5.

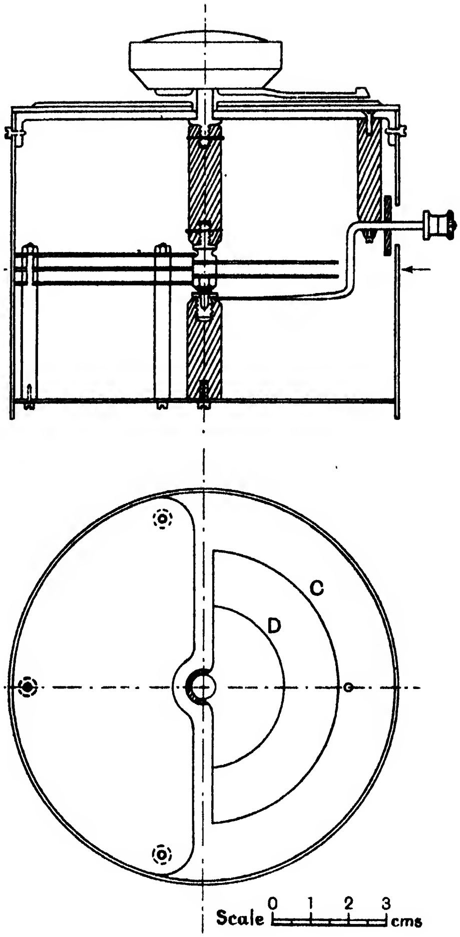

Fig. 3

Type (2). *Flat Semicircular Plates*

The preceding experimental results indicated that the plate edge capacity was not serious. Two condensers "*C*" and "*D*" were then constructed as shown in Fig. 3 with ordinary flat semicircular plates, the clearance between the two systems being about 5 mm. when in the minimum position.

"*C*" and "*D*" were identical with the exception of the radii of the pairs of moving plates, and the results on the two condensers are embodied in Tables VI and VII.

Table VI

Plates: 2 moving (insulated), 3 fixed. Air-gap: 1 mm.
Radius of moving plates: $\begin{cases} C = 3{\cdot}5 \text{ cm.} \\ D = 2{\cdot}1 \text{ cm.} \end{cases}$
Screen: As before

Table VII

Setting	Capacity	Ratio: max./min.
Minimum *C*	5·3 $\mu\mu$ F.	12·5
Maximum *C*	66·7 $\mu\mu$ F.	
Minimum *D*	3·5 $\mu\mu$ F.	7
Maximum *D*	25·0 $\mu\mu$ F.	

The measurements on "*C*" were repeated when one moving plate had been removed, and although the maximum was halved the minimum only decreased by 0·5 $\mu\mu$ F., thus confirming that the mutual edge effect of the plates is small.

The component capacities constituting the minimum value of "*D*" were then obtained by repeating measurements when various parts had been removed. These are given in Table VIII.

Table VIII. *Condenser "D." Component capacities of Minimum Setting*

(α)	Capacity due to	moving plates	1·3 $\mu\mu$ F.
(β)	,,	short spindle and boss	0·6 $\mu\mu$ F.
(γ)	,,	ebonite lead support	0·0 $\mu\mu$ F.
(δ)	,,	bottom footstep bearing	0·1 $\mu\mu$ F.
(ϵ)	,,	lead out alone	1·5 $\mu\mu$ F.
		Total	3·5 $\mu\mu$ F.

The above capacities are not strictly additive, but probably represent the truth to $\pm$ 0·1 $\mu\mu$ F. "α" and "δ" are unavoidable, while "β" could not be reduced by more than a few tenths at the most. "ϵ," the largest individual item, consisting of over 40 per cent. of the total, is due to the lead out, which places a severe limitation on the smallest attainable minimum. In this particular case, about $\frac{2}{3}$ of the lead capacity was located in the last few cms. which passed through the hole in the case. The diameter of the lead out was 2 mm., for mechanical rigidity, while the hole in the screen was drilled out to 1 cm.

In the light of the results given in Table VIII it is not considered probable that a completely screened condenser of 20 $\mu\mu$ F. variation can be constructed with a minimum value of less than 3 $\mu\mu$ F.

As the insulated lead is not led through the screen by means of an ebonite or quartz bush, the possibility of dust finding its way inside has to be guarded against. For this purpose, an ebonite disk has been fixed just inside the hole in the screen to deflect any stray particles to the bottom of the instrument.

Summarizing, the more useful and generally efficient type is that with flat semicircular plates with the moving system insulated, both from the points of view of absolute minimum, ratio of maximum to minimum and ease of construction, there being no doubt that uniformity of air-gap can be more readily obtained by the employment of flat plates.

In those instruments described, the contact of the bottom bearing has been deemed sufficient, but safer practice is to make soldered connexion by means of a small spiral of phosphor-bronze strip, the movement then being provided with the requisite stops.

The dielectric losses will be seen to be negligibly small as the ebonite insulating pillars are long and the capacity in the dielectric itself is only of the order of a few tenths of a micromicrofarad.

Errors in Calibration and Use

(1) *The Manner of Disconnexion.* The correct way to disconnect a screened condenser from a circuit in precision work is to disconnect the lead on the insulated side and bend the end about a cm. away from the terminal, disturbing the leads, and hence altering the lead capacity, as little as possible. No other disconnexion should be made, otherwise the mutual capacities of the system will be affected. However, there is one small error introduced. When the lead is disconnected, a small capacity C_t is introduced in series with the true condenser mutual capacity C_m. Thus, on disconnexion, the capacity in the circuit is really diminished by

$$C_m - \frac{C_m C_t}{C_m + C_t}$$

$$= C_m - C_t \text{ in all practical cases, as } C_m >> C_t.$$

C_t is shown below to be very small and as it is sensibly constant, the condenser can be calibrated and used under the condition of "single disconnexion" (denoted by "S.D." subsequently for brevity).

The value of the capacity C_m can be arrived at by an application of the elegant method originated by Hartshorn* to allow for the leads in a bridge for the measurement of small capacities. If the measurements be carried out on a bridge of the Schering type, then in a three terminal device, if two terminals be connected to one arm of the bridge and the third be earthed, the earth-capacities to the third are thrown across one of the ratio arms or the whole bridge and eliminated, while the bridge balance is restored by adjustment of the condenser across the ratio arm. The procedure is given summarily for completeness.

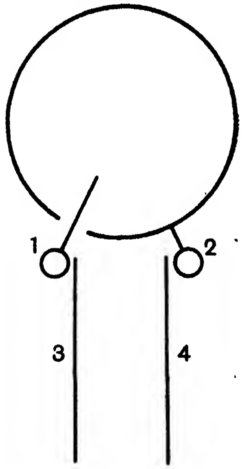

Fig. 4

In Fig. 4 let 1 and 2 be the two terminals of the condenser and let 3 and 4 be the leads to the bridge arm. Then

(α) Connect 1 to 3 and 4 to 2, obtain bridge reading. The effective capacity between the leads

$$= C_{12} + C_{14} + C_{32} + C_{34}.$$

(β) Disconnect 3 from 1 and earth 1. Effective capacity

$$= C_{32} + C_{34}.$$

(γ) Repeat for other lead, similarly the effective capacity

$$= C_{14} + C_{34}.$$

(δ) Disconnect 3 and 4 and earth 1 and 2. The only capacity remaining is C_{34} with the exception of the earth capacities, which are eliminated.

Hence $$C_m = C_{12} = (\alpha + \delta) - (\beta + \gamma).$$

Measurements were made on condenser "D" when set near its minimum by the four reading and the S.D. methods of allowing for the leads. Three gauges of lead wire were employed in order to investigate the variation in the value of C_t. The results are given in Table IX.

Table IX. *Lead Capacities on Disconnexion*

Gauge of lead wire	Capacity by S.D. $\mu\mu$ F.	Capacity C_m $\mu\mu$ F.	Difference C_t $\mu\mu$ F.
No. 22	$3{\cdot}6_5$	$3{\cdot}7_0$	$0{\cdot}1_8$
30	$3{\cdot}7_2$	$3{\cdot}8_3$	$0{\cdot}1_1$
36	$3{\cdot}7_3$	$3{\cdot}8_3$	$0{\cdot}1_0$

The discrepancy in the value of C_m in the first case is due to the fact that disconnecting the comparatively thick leads altered slightly their mutual capacity C_{34}. The differences in the last column which represent the values of C_t accurately to 10 per cent. are in each case evaluated assuming $C_m = 3{\cdot}8_3$ $\mu\mu$ F. The particulars of the terminals were as follows:

Approx. height	1	cm.
,, diameter	0·5	,,
,, distance apart	3	,,

(2) *Effects of Imperfect Shielding*. Although in the designs discussed, the shielding almost approaches the theoretical case, there must of necessity be a lead out and terminal from the insulated system. This terminal with any of the exposed system of which it forms a part has an earth capacity, which makes it necessary to examine the equations governing the case when imperfect shielding is present. Initially, suppose two conducting bodies 1

* *Proc. Phys. Soc. London*, **36**, Part v, 1924.

and 3 connected together in free space in the presence of a third body 2. Let E_1 and E_2 be the charges on each respectively. Then if V_1 and V_2 be the potentials:

$$E_1 = (C_{1e} + C_{3e})V_1 + (C_{12} + C_{23})(V_1 - V_2),$$
$$E_2 = (C_{2e}) \qquad V_2 - (C_{12} + C_{23})(V_1 - V_2),$$

where "C_{pq}" is the mutual capacity between bodies "p" and "q," and "C_{pe}" is the earth capacity of body "p." Then

$$i_1 = (C_{1e} + C_{3e})\frac{dV_1}{dt} + (C_{12} + C_{23})\frac{d}{dt}(V_1 - V_2),$$

$$i_2 = (C_{2e}) \qquad \frac{dV_2}{dt} - (C_{12} + C_{23})\frac{d}{dt}(V_1 - V_2).$$

As the value of capacity is equal to the current divided by the rate of change of potential difference across it, we have

$$K_1 = i_1\Big/\frac{d}{dt}(V_1 - V_2) = (C_{12} + C_{23}) + (C_{1e} + C_{3e})\frac{dV_1}{dt}\Big/\frac{d}{dt}(V_1 - V_2)$$

and $$K_2 = -i_2\Big/\frac{d}{dt}(V_1 - V_2) = (C_{12} + C_{23}) - (C_{2e}) \qquad \frac{dV_2}{dt}\Big/\frac{d}{dt}(V_1 - V_2).$$

If now the condition be introduced that the screen and one set of plates, represented by 2, completely surrounds 1, but not 3, then $C_{1e} = 0$.

K_1 and K_2 give two possible definitions of capacity but of these K_1 is the only really useful one.

If now the new condition be introduced into the expression for K_1 and C be written for $(C_{12} + C_{23})$, the expression for the effective capacity between terminals becomes

$$C + C_{3e}\frac{dV_1}{dt}\Big/\frac{d}{dt}(V_1 - V_2),$$

which shows that the small term involving "C_{3e}" which is the earth capacity of the insulated terminal is not quite independent of the potential distribution.

In the particular case examined, very careful measurements made with the condenser supported high above the bench and when standing on a large sheet of metal, insulated by paraffin blocks in each instance, enabled an upper value of 0·02 $\mu\mu$ F. to be given to the coefficient C_{3e}. In radio-frequency circuits, it is usual practice to earth the shield, in which case $V_2 = 0$ and the magnitude of C_{3e} then represents the absolute error.

The small capacities given in the tables were obtained on a Schering Bridge with 10 : 1 ratio arms in which was incorporated a vernier standard condenser reading in tenths of a micromicrofarad.

From the above examination of the possible errors, it will be seen that if the condenser be calibrated, disconnecting only on the insulated terminal, the capacity readings can be relied upon with certainty to 0·2 $\mu\mu$ F. at all parts of the scale, while the normal error will be less than this, if leads of fine wire be employed.

Finally, I wish to thank Mr D. W. Dye, B.Sc., for his kind interest and encouragement during the course of the work.

THE "MOLECULAR MOVEMENTS" OF SENSITIVE MOVING-MAGNET GALVANOMETERS. By PROF.

A. V. HILL, F.R.S., Dept. of Physiology and Biochemistry, University College, London.

[*MS. received*, 14*th October*, 1926.]

ABSTRACT. A discussion is given of the random movements of the system of a sensitive moving magnet galvanometer, on the assumption that these have a mean energy equal to $\frac{1}{3}$ of that of a gas molecule at the same temperature. It is shown that these movements are of importance at sensitivities now practically attainable, and certain deductions are made in connexion with the design of galvanometer systems.

In a recent paper Ising (1) has discussed a natural limit to the sensitivity of galvanometers, placed by the onset of what may really be called molecular movements of their systems. His treatment applies particularly to the case of a moving coil instrument, and he gives reasons to suppose that the disturbances visible after amplification by the thermal relay [Moll and Burger (2); see also Downing, Gerard and Hill (3)] are really due to unavoidable molecular causes. As his reasoning does not apply directly to moving magnet galvanometers*, I have calculated the natural limits to the sensitivity of some instruments actually constructed by Mr A. C. Downing (see (4)) with the following striking results.

In an oscillation governed by the equation

$$MK^2 \frac{d^2\theta}{dt^2} + p\frac{d\theta}{dt} + a\theta = 0,$$

the undamped period is given by

$$t_0 = 2\pi\sqrt{\frac{MK^2}{a}} \qquad \ldots\ldots(1),$$

where MK^2 is the moment of inertia of the moving system and $a\theta$ the restoring couple.

The potential energy of the displaced system, in any position θ, is $\frac{1}{2}a\theta^2$, which, substituting from (1) for a, and evaluating numerically, is

$$19{\cdot}7\, MK^2\theta^2/t_0^2.$$

Let us assume that $\bar{\theta}$ is the root mean square deflection (of the moving system), from its zero position, due to molecular causes. Then the mean energy is

$$19{\cdot}7\, MK^2\bar{\theta}^2/t_0^2,$$

which we may equate to 2×10^{-14} erg, the mean energy of a gas molecule at room temperature, per degree of freedom. This leads to the equation

$$\bar{\theta} = \frac{3{\cdot}2 \times 10^{-8}\, t_0}{\sqrt{MK^2}} \qquad \ldots\ldots(2).$$

Let us now assume that we desire to read the position of a beam of light, to the nearest 1 mm., at a distance of 3 metres. Then the mean displacement from the true position at any time must not be greater than (say) $\frac{1}{2}$ mm., so that the mean angular displacement of the *mirror* must not be greater than $\frac{1}{12000}$ radian. Substituting this in (2) we find

$$\frac{t_0}{\sqrt{MK^2}} = 2600 \qquad \ldots\ldots(3).$$

This, for a system of given size, shows the maximum period allowable, and therefore the greatest sensitivity. It is instructive to calculate some actual values.

* In which the damping is mainly by the air, and only in small part electromagnetic.

Galvanometer A. Mirror, $2 \times 1 \times 0{\cdot}05$ mm.; 12 magnets, each $1 \times 0{\cdot}25 \times 0{\cdot}1$ mm. $MK^2 = 2{\cdot}25 \times 10^{-6}$.

Galvanometer B. Mirror, $2 \times 2 \times 0{\cdot}05$ mm.; 12 magnets, each $1{\cdot}2 \times 0{\cdot}3 \times 0{\cdot}13$ mm. $MK^2 = 7{\cdot}5 \times 10^{-6}$.

For galvanometer A, the maximum allowable period so calculated is 3·9 secs.; for galvanometer B, it is 7·1 secs.

Let us consider what these mean in terms of sensitivity: for a galvanometer of 10 ohms resistance, and of figure of merit 20,000, the value of 1 mm. at 3 metres distance is $4{\cdot}5 \times 10^{-11}$ amp. at period 3·9 secs., and $1{\cdot}3 \times 10^{-11}$ amp. at period 7·1 secs.

Thus, even on the most perfect support, galvanometer A, in spite of its high "figure of merit," is incapable of being pushed to very great sensitivities, while galvanometer B can go only about three times as far.

If the galvanometer be used, not at 3 metres but at $1\frac{1}{2}$ metres distance, the reading may be made to the nearest $\frac{1}{2}$ mm. with the above periods; or if we still intend to read only to the nearest 1 mm. the maximum allowable t_0 has twice the above values. This means that we may read on the nearer scale to twice the sensitivity. Thus although simple calculation from the figure of merit indicates that the sensitivity increases as the square of the period, these molecular movements, at high sensitivities, entail the consequence that the *effective sensitivity varies only as the first power of the period.*

It is obvious of course that by photographic methods we may obtain a record capable of having these molecular movements largely smoothed out. A record, obtained at 1 metre distance, with a mean displacement of $\frac{1}{3}$ mm., should be capable of being smoothed to the nearest $\frac{1}{10}$ mm., and so a $3\frac{1}{3}$-fold effective increase in sensitivity obtained.

From formula (3) it might be imagined that all we have to do, in order to increase the maximum effective sensitivity, is to increase the moment of inertia: t_0 increases in proportion to $\sqrt{MK^2}$, so that—*on the assumption of a constant figure of merit*—the maximum effective sensitivity should increase as MK^2. The assumption, however, requires examination. We may increase MK^2 without decreasing the figure of merit by one method only—increasing the number, and perhaps to some extent the thickness and width of the magnets. If we increase their length l—neglecting the weight of the mirror—the moment of inertia increases as l^3 while the magnetic moment increases only as l. The sensitivity, being proportional to the magnetic moment, increases as l: the square of the period, being proportional to the moment of inertia, increases as l^3: thus the figure of merit varies inversely as the square of the length of the magnets. Experience, moreover, has shown the great increase in figure of merit associated with a decrease in the length of the magnets. It is possible that in this respect Mr Downing (4) has attained all that is practically possible.

It remains only to test experimentally the effect of increasing the thickness and width of the magnets. With cobalt steel of sufficient retentivity and properly hardened no great decrease in the ratio (magnetic moment)/(moment of inertia) may result from so doing. If so, this should be the most effective way of avoiding molecular movements at high sensitivities.

Owing to the mechanical and other disturbances obtaining in London it is not possible to apply a really satisfactory test of the limits of sensitivity calculated above. On occasions, however, they may be reached, so that their existence, even here, is of importance.

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(3) Downing, Gerard and Hill, *Proc. Roy. Soc.* B, **100** (1926) 223.
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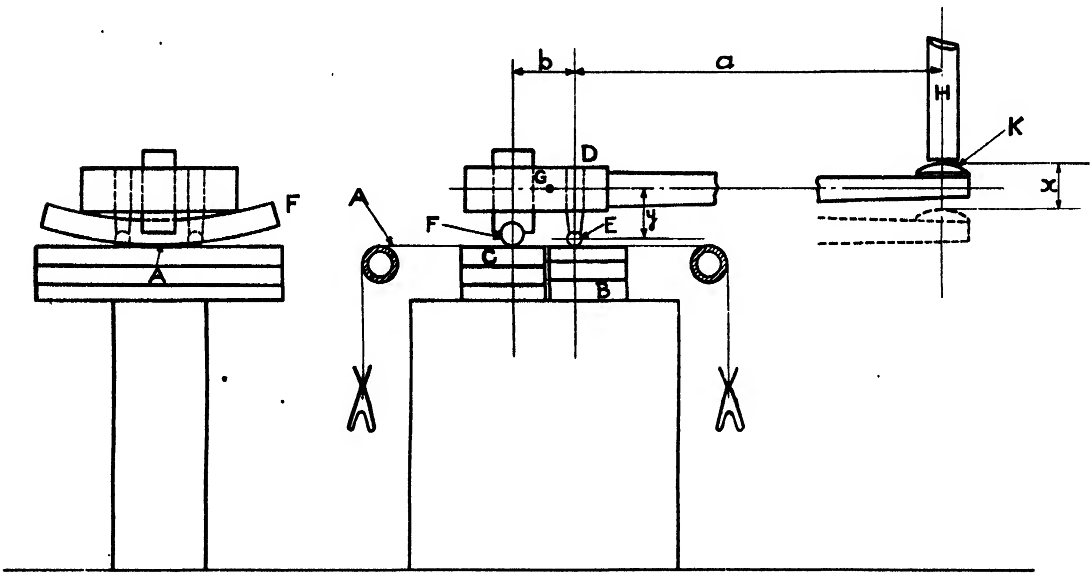
THE MEASUREMENT OF FINE WIRES.

By G. A. TOMLINSON, B.Sc., National Physical Laboratory.

[*MS. received, 6th July,* 1926.]

ABSTRACT. A mechanical method of measuring fine wires is described. The measurement is made at a point and with a very light pressure so that no deformation occurs. The accuracy of the measurement is 0·00001 in.

In the measurement of fine wire, such as that used for hot filaments, it is necessary to reach a high degree of accuracy in order to obtain only a moderate percentage accuracy. It is not possible to attain this accuracy with any of the usual measuring appliances, such as the micrometer or measuring comparator, since the wire must then be measured between flat faces under a pressure which will deform it appreciably. Further, by comparison with its diameter, a very large length of wire is placed between the measuring faces, and the result tends to represent always the maximum diameter.



A simple method of making this measurement giving results accurate to about 0·00001 in. has been devised in the Metrology Department of the National Physical Laboratory. This is shown diagrammatically in the figure. The fine wire A, which may have a light spring clip attached to each end if necessary to keep it from coiling, is laid across two piles of slip gauges B and C which are wrung transversely to a supporting gauge standing on a face plate. The pile B is greater than C by an amount equal to the nominal diameter of the wire to the nearest 0·0001 in. Hence the difference in level between the top of the wire over pile C and the face of pile B lies between $\pm$ 0·00005 in.

This difference of level is measured by the tilting lever D, which rests on two small steel balls E and a slightly curved cylinder F, the curvature being indicated, much exaggerated, in the end view. The lever is first placed with its three feet all on the face of pile B, without the wire present, and the height of a sector K at the end of the arm is measured by the micrometer H. It is then replaced with the ball feet still on B and the cylinder bearing on the top of the wire over the pile C and the height of the sector is again observed.

The following example will perhaps make the procedure clearer:

Nominal diameter of wire, 0·001 in.

Pile $B = 0{\cdot}10800$ in. Pile $C = 0{\cdot}10700$ in.

Magnification constant of lever, 28·8.

First micrometer reading on B, 0·9145.

Second ,, wire, 0·9140.

$\dfrac{\text{Difference}}{28{\cdot}8} = \dfrac{0{\cdot}0005}{28{\cdot}8} = 0{\cdot}00001_7$.

Diameter of wire, $0{\cdot}00100 + 0{\cdot}00001_7 = 0{\cdot}00101_7$.

The finish and curvature of the cylindrical foot of the lever are important. It should be highly polished and of such small curvature that the exact location of the wire under the cylinder is not of importance. Thus if the radius of curvature is 125 inches, the wire may be placed anywhere in the central 1/10 in. without affecting the result by more than 0·00001 in. This curvature, or even less, is easily obtained by bending an initially straight cylinder.

The pressure of the cylinder on the wire can be readily found by feeding the micrometer downwards until the lever becomes unstable and falls. If x is the measured movement of the micrometer required to overturn the lever, the pressure with which the cylinder bears on the wire is

$$p = \frac{wmy}{a^2} x = kx,$$

where w = weight of the lever,

m = magnification constant,

y = height of the centre of gravity above the centres of the balls,

a = length of long arm.

A suitable pressure is about 0·1 gm. which is sufficient to bring the wire definitely into contact with the slip gauge, and is at the same time too small to produce any appreciable elastic deformation. This deformation has been calculated, in the rather extreme case of a copper wire of diameter 0·0004 in., to be less than $0{\cdot}2\,\text{in.} \times 10^{-6}$ and is thus entirely negligible.

An incidental advantage of the method may be added in conclusion, namely that the apparatus is very simple, robust and inexpensive.

THE TESTING OF CURRENT TRANSFORMERS.

By R. G. ISAACS, M.Sc., A.M.I.E.E., University College, Swansea.

[*MS. received*, *25th August*, 1926.]

ABSTRACT. A method of testing the phase angle and ratio of current transformers using a polyphase wattmeter and phase shifter is described. Results of tests are given showing the effect, on the accuracy of a transformer, of allowing it to be run with the secondary open-circuited.

For obtaining the ratio and phase angle error of current transformers the A.C. potentiometer method described by Mr A. C. Jolley* in this *Journal* some time ago is undoubtedly one of the most accurate. Unfortunately A.C. potentiometers very rarely find a place in supply authorities' test rooms. Also if the full possible accuracy of the potentiometer is to be

* *Journ. Scient. Instr.* **3**, 2.

obtained absolute steadiness of supply is essential, a condition which is unusual outside laboratories. Most modern test rooms have however precision type dynamometer wattmeters and means of varying the phase angle between current and voltage in constant use, and a method of current transformer testing not involving anything beyond this should be very useful to them. In the tests to be described the equipment consisted of a Drysdale standard polyphase wattmeter, the current ranges being 5, 10, 25 and 50 amperes. Phase angle variation was obtained by the use of a Drysdale Phase Shifter. The method adopted for measuring the phase angle between the primary and secondary currents was a modification of that put forward by A. E. Moore*, the connexions being shown in Fig. 1.

In making the test the double throw switch is closed to complete the volt coil circuit on the side in which the series coil is connected to the secondary of the transformer. The phase shifter is then adjusted until the wattmeter is at zero. The switch is now thrown over to the other volt coil and the reading of the wattmeter taken.

It can easily be shown that $\sin\beta = \frac{W}{VI_p}$, where β is the angle between the primary current and the secondary current reversed, W is the wattmeter reading, V the voltage on the volt

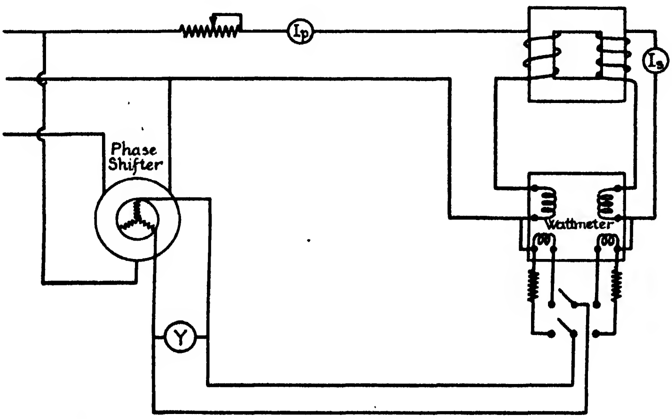


Fig. 1. Connexions for Phase Angle and Ratio Tests

coils and I_p the current in the primary. The only assumptions made are that there is no appreciable interference between the two systems of the wattmeter and that the two volt circuits are identical. Both these assumptions are justified in a wattmeter of this type and this would seem to be a useful method where one polyphase wattmeter is the only instrument available. It will be seen that a value of sin β can also be obtained by adjusting for zero wattmeter reading with the two-way switch on the primary side, I_s the secondary current now taking the place of I_p in the formula. Usually however the first method will give the greater accuracy if a wattmeter having current ranges of 5 amperes and multiples of 5 is used since the range on the primary side can be set to the lowest value consistent with the actual current at which a test is desired and hence the maximum reading on the wattmeter. In all tests of this kind the usual difficulty is that the wattmeter deflection is extremely small due to the fact that the volts and current are within a few degrees of being in quadrature. With the wattmeter used in these tests however it is possible to increase the volt coil current to 5 or even 10 times normal without danger of overheating, thus getting a reasonable wattmeter deflection. A further check on the above results can be made by noting the angle through which the phase shifter must be moved to get zero reading with the switch closed

* *Journ. Inst. Elec. Eng.* 58.

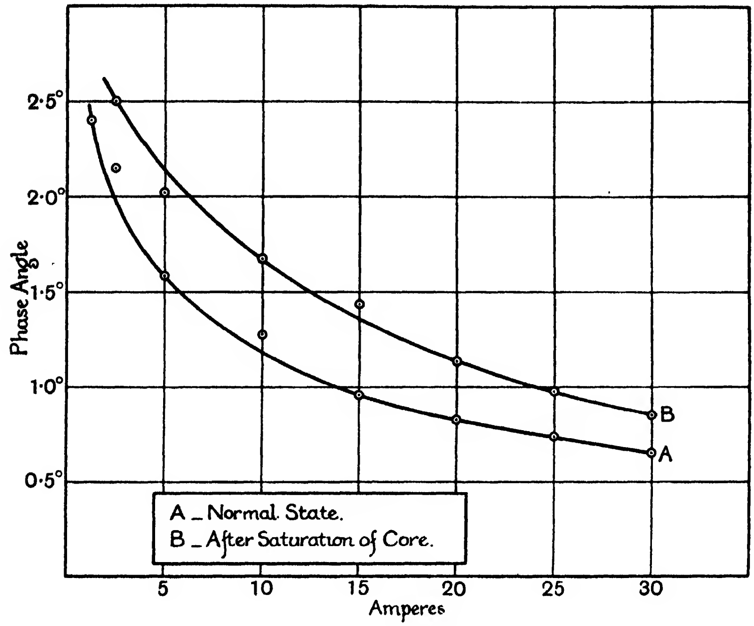


Fig. 2. Phase Displacement

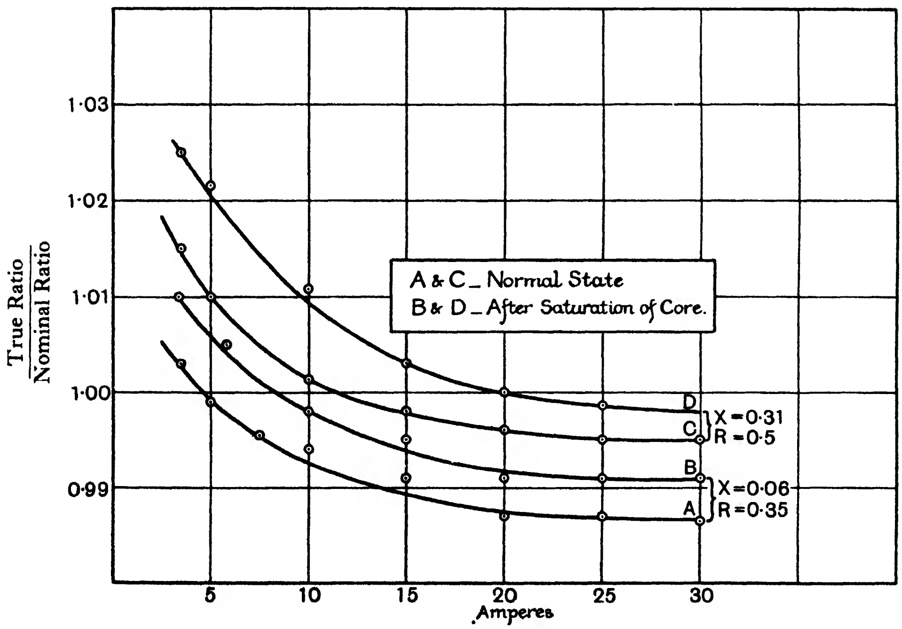


Fig. 3. Ratio Tests

on the secondary volt coil side, and zero reading with it closed on the primary volt coil side. A typical result obtained in this way for a 6 to 1 transformer was as follows:

β with primary wattmeter at zero 0·84°,
β with secondary wattmeter at zero 0·86°,
β from movement of phase shifter 0·88°.

The above method was used to investigate the effect on the accuracy of a certain current transformer of previously running it with the secondary open-circuited. It is generally stated that such an action results in the core being left in an abnormal magnetic state which brings about serious changes in phase angle and ratio. The transformer tested was of a well-known British make, 6 to 1 ratio and 50 periods. A series of readings were taken from full load downwards, first with the transformer iron in its normal condition and then after the secondary had been open-circuited. The results are shown in Fig. 2. In addition to the series coil of the wattmeter and the ammeter, further resistance and inductance were added to bring up these values to $R = 0{\cdot}5$ ohm and $L = 1$ millihenry which give approximately 15 volt-amperes at full load. It will be seen that the phase angle is increased by about 30 per cent.

The other important characteristic, the ratio, can be measured without any change in the connexions. The phase shifter is moved round 90° from the zero position, that is, until the current and volts are in phase. This is done for each position of the two-way switch, the ratio of the two readings giving the ratio of the transformer. This method, while obviously not so accurate, was found in practice to give results agreeing quite closely with those obtained by the potentiometer method. A set of curves for two different values of the load, showing the effect of the secondary having been opened, are shown in Fig. 3. The core was brought back to its normal condition by passing an alternating current through the secondary, the primary being open, and reducing it gradually to zero. Careful tests showed that a current as low as 0·2 amp. removed all trace of the previous saturation; with 0·1 amp. the phase angle was still slightly greater than in the normal condition. This result suggested that very low currents in the primary would produce the abnormal condition, if the secondary were open-circuited, and it was found that a primary current of about 1 amp. produced as much change in the phase angle and ratio as did the full load of 30 amps.

PURE METAL ELECTRODES IN ELECTRIC DISCHARGE TUBES AND SOME RESULTS. By JAMES TAYLOR, M.Sc., Ph.D., A.Inst.P.*, The University Physical Laboratory, Utrecht.

[*MS. received*, 16*th October*, 1926.]

Sodium Electrodes

Many years ago Warburg (1) put forward a method for the introduction of pure sodium into discharge tubes, electrolytically through the glass walls. Several applications of the method were made (2). Recently a similar process has been utilized by Burt (3) for the introduction of sodium into metal filament lamps by utilizing a discharge between the heated filament and the glass walls which were partially immersed in a bath of molten sodium nitrate at about 350° C. A suitably high potential (about 300 volts) must be maintained between the heated filament (kathode) and the glass walls (anode).

* Fellow of the International Education Board.

In such a way pure sodium may be introduced upon the electrodes of such discharge tubes as neon lamps. The neon-discharge takes the place of the heated filament. The action is to a large extent reversible: by making the glass walls kathode instead of anode, sodium may be actually removed from the discharge tubes.

Metal Electrodes

In order to investigate the properties of electric discharges in rare gases between pure metal electrodes, the writer has used a discharge tube consisting of a tungsten wire electrode surrounded by a coaxial tungsten wire spiral, the geometrical disposition being such that discharge always took place from the inner tungsten wire to the surrounding spiral. The electrodes could be heated to white heat in high vacuum to obtain pure metal surfaces, and carefully purified argon or other gas could then be introduced. Alternatively, by heating one filament in the argon a deposit of tungsten could be condensed upon the other electrode and its properties investigated.

Further, pure metal electrodes of various metals may be constructed by a modification of the method of metallic evaporation which I described recently in connexion with celluloid films (4).

Some Applications and Results

Some time ago the writer in collaboration with Mr Clarkson put forward a method of capacity and high resistance measurement using the "flashing" properties of neon tubes (5). At a later date some of the factors which gave rise to error in the measurements were described and certain expedients to overcome them were given (6). Nevertheless a really satisfactory solution was not obtained. By introducing sodium upon the electrodes of the neon lamps, in the manner described above, they may be "stabilized" considerably, their working voltages reduced, and their useful range of resistance and capacity measurement extended. Employing this method I have been able to measure accurately, by the method of timing "flashes" by a stopwatch (5), capacities so low as 0·001 microfarad, when care was taken to efficiently insulate the circuit. The discharge tube used was a Philip's tungsten arc lamp (small tungsten sphere electrodes separated by a few mm., filling gas, neon at about half an atmosphere). The tungsten electrodes only were utilized in discharge.

The preliminary study of the sparking potentials of such tubes yielded very interesting results. For parallel electrode tubes it was found that the effect of introducing sodium upon the kathode was to diminish the sparking potential progressively as the amount of sodium was increased, until a constant minimum value was attained. It may be assumed, in accordance with Langmuir's Theory (7), that a film of atomic thickness of sodium upon the electrode will act in all ways as a sodium electrode. If the quantity of sodium is insufficient for this then there will be bare patches. It was concluded that for the type of tube in which the electric field was uniform over considerable areas, the sparking potential value was a function depending upon the nature of the kathode over considerable areas. The sparking potential is thus to be regarded as a gross effect of ions.

Experiments with pure tungsten electrodes in argon gave some interesting results. The sparking potentials were determined utilizing very small discharges (a few microamperes). The first discharge passed less readily than the following ones and the sparking potential gradually decreased under the action of the discharge to a constant lower value. The higher sparking potential values did not appear again when the tube was rested, the decrease was consequently of a permanent nature and may be attributed to the absorption of gas at the cathode surface under the action of the discharge, an absorption which apparently was not produced in the non-ionized gas. It is consequently impossible to maintain a pure metal surface of tungsten in an electric discharge and this is probably also the case with other

metals. The value of the sparking potential for the first discharge is alone definitely characteristic of the metal comprising the electrode. The importance of this result in electric discharge theory is obvious.

I have great pleasure in acknowledging here my indebtedness to the International Education Board for the Fellowship which enabled this work to be carried out, to Prof. Ornstein for continued advice and assistance, and to Mr Kuipers for his care in constructing all the tubes and glass work used in the experiments.

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(5) Taylor and Clarkson, *Journ. Scient. Instr.* **1** (1924) No. 6.
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BRITISH SCIENTIFIC INSTRUMENT RESEARCH ASSOCIATION

Certain of the reports of the British Scientific Instrument Research Association have been released for publication and by the kindness of Sir Herbert Jackson, F.R.S., Director of Research, we have received a number of these for reproduction in this *Journal*. It is proposed to include one of these reports in each issue as the information they contain should be of considerable practical value, and it is hoped that they will prove of assistance to all those concerned in fine instrument work.

REPORT No. 5. NOTE ON SHELLAC LACQUER. (May, 1922.)

A Short Report of Work carried out by H. L. SMITH, B.Sc., F.I.C.

The attention of this Association was called to the fact that, compared with some of the older lacquers, there was tendency for a certain want of brilliancy and sparkle in many samples of modern lacquer. It seemed likely that the slight fogginess observed would be ascribable to the presence of matter disseminated in an extremely fine state through the lacquer and of different refractive index from it. If that were the cause the remedy would be either fine filtration or separation of material by long settling or by centrifugal means. Each of these methods has been in use and from experiments made it appears that good filtration can be effected through about 1½ inches of fine sand, *e.g.* silver sand previously washed and dried. The sand may be supported conveniently on filter paper or a plug of cotton wool. As shellac contains not only resinous matter soluble in alcohol but also small and variable quantities of wax insoluble in alcohol, the object of the filtration is to remove this wax which is suspended in fine particles throughout the resinous solution and so causes turbidity.

Lacquer so filtered has been considered to give a very good and bright result, but good as such filtered lacquer is, some users have considered that it is not quite so brilliant still as certain lacquers of which they had previous experience some years ago. Experiments were, therefore, made on the use of various materials which could be mixed with the

lacquer. Some of these have been from time to time recommended; the following are those to which special attention has been paid:

(1) *Boracic Acid.* This was tried in the proportions of 0·1 and 0·2 parts by weight to 100 volumes of the lacquer. There is no evidence from the trials made that any marked improvement can be obtained by the use of this material.

(2) The use of *various oils* which have been considered does not give any results in the way of increased brilliancy and there are objections to their use in their subsequent behaviour.

(3) *Other Resins.* The substitution of part of the shellac by its equivalent of such resins as sandarac, elemi and soft copals has been tried. Many other resins which might seem to be worth trying, *e.g.* dammar, are so insoluble in alcohol as to be useless for the purpose. Of the resins tried the only one which has given results of a promising character is copal, and a lacquer made with the addition of this resin is considered to be distinctly brighter and clearer than one made from shellac alone.

The following mixture has given good results:

Shellac	95 grams
Copal	35 ,,
Alcohol	1 litre

or, in ounces and pints, and in quantities so as not to have small fractions:

Shellac	17 ounces
Copal	$6\frac{1}{2}$,,
Alcohol	8 pints

This amount of copal appears to be about the maximum which can be used as a substitute for part of the shellac. With smaller quantities of copal there is still improvement but the proportion mentioned appears to give the best results.

It will be found that the copal does not entirely dissolve nor at present has any sample of copal been obtained which, in this or smaller proportions, can be entirely dissolved. When the copal is as fully dissolved as possible the solution is thoroughly filtered in the manner suggested above.

The addition of copal reduces the colour of the lacquer and if a more pronounced colour be desired the most suitable substance appears to be a little gamboge. The maximum quantity of gamboge suggested is 10 grams to the litre of lacquer, or $1\frac{3}{4}$ ounces to the gallon. As only the yellow resin of the gamboge dissolves, leaving the gummy matter present in the gamboge undissolved, the gamboge should be added before filtration.

Selection of Copals

The term "copal" is very widely applied to many resins from different sources which are used in varnish making; the majority are either insoluble or very slightly soluble in alcohol and are useless therefore for lacquers. The copal referred to in the above formula was purchased as a soft manilla copal. It had a yellow colour and was readily soluble in alcohol in the sense indicated above. Probably no copals are completely soluble, at least none which have been obtained by us is so. In working with some samples it has been noticed that an apparently feebly soluble copal becomes much more readily soluble if freshly crushed just before addition to the lacquer, and samples which were at first rejected as being useless have been found to be quite usable after fine crushing. In any case it seems desirable that copal should be bought from a sample and tested to find if it is sufficiently soluble for the purpose, and the following note might be of help: Messrs. Evans Sons, Lescher &

Webb, of St Bartholomew's Close, have submitted several samples of copal. The two following appear suitable for the purpose of lacquer making:

(1) Registered No. 4029 quoted at 112*s*. per cwt. in original bags of 1¼ cwt.

(2) Registered No. 4030 quoted at 105*s*. per cwt. in original bags of 1¼ cwt.

These are apparently not stocked by the firm and can only be supplied in the original bags. If, however, there were a sufficient demand for such copals, it is probable the firm would consider stocking and supplying in smaller quantities. In actual practice it has not been found possible to distinguish between these two samples of copal.

Note on Alcohol

This should be of good quality and of full strength. It should leave very little or no residue on distillation. Industrial alcohol, described as of 64° over-proof, is only made and sold under strict Excise control and is seldom unfit for the making of lacquers. It is, however, frequently cloudy especially towards the bottom of a tin, but as it is here suggested that all lacquer should be carefully filtered before use, any such cloudiness will be removed during the making of the lacquer.

Note on Shellac

It does not appear possible at present to frame a useful specification for shellac. It varies very much in quality and may be, and occasionally is, adulterated with colophony resin. The presence of this resin for lacquer purposes is to be deprecated. None of the samples collected from various sources for the experiments here was found to contain colophony. As there does not appear to be any accepted standard for shellac, the appearance is the best guide at present. An orange shellac of clean and bright appearance gives satisfactory results. First-class shellac seems generally to be supplied in fairly large flakes in which dirt and other foreign matter would be easily noticeable. The shellac should be completely soluble in alcohol except in so far as the wax present is concerned.

NEW INSTRUMENT

THE HEAPE AND GRYLLS MACHINE FOR HIGH SPEED PHOTOGRAPHY. By W. H. CONNELL, F.R.A.S., F.R.G.S., A.I.M.E.

[*Editor's Note*. Recently, through the courtesy of Messrs Vickers, Ltd., several N.P.L. officials were present at a private exhibition in London of some extraordinary slow motion films, following which it was felt that a description, no matter how brief, of the special rapid cinema machine, by the aid of which these films were made, would be of interest to our readers.]

History

The conception of the idea embodied in this wonderful piece of mechanism was due in the first instance to Mr Walter Heape, F.R.S. and Mr H. B. Grylls, whilst the working out of the scheme in its practical design and construction was done by Messrs Cooke, Troughton and Simms, Ltd., at their Buckingham Works, York, to the order of the British Government.

Purpose

Whilst the Heape and Grylls Machine has been specially designed for photographically recording the movements occurring in high speed phenomena, such as the bursting of shells and shrapnel, penetration of armour plate by projectiles, recoil of guns, the action

of automatic quick-firing guns, and similar subjects of investigation in practical ballistics, the utility of the machine is, of course, not confined to military uses, and many other subjects of scientific investigation by its aid, which have hitherto defied analysis, where a slowed down record of extremely rapid motion would be invaluable, suggest themselves to one's mind. By its use cinema pictures can be taken on ordinary cinema film at any speed from 500 to 5000 per second, as required, and this either as single or stereoscopic pairs of views.

Design

The principle on which this method of rapid cinematography is based is the continuous and synchronised movement of film and lens in order that there shall be no relative movement between film and image cast by the lens, and, for this purpose, the machine consists

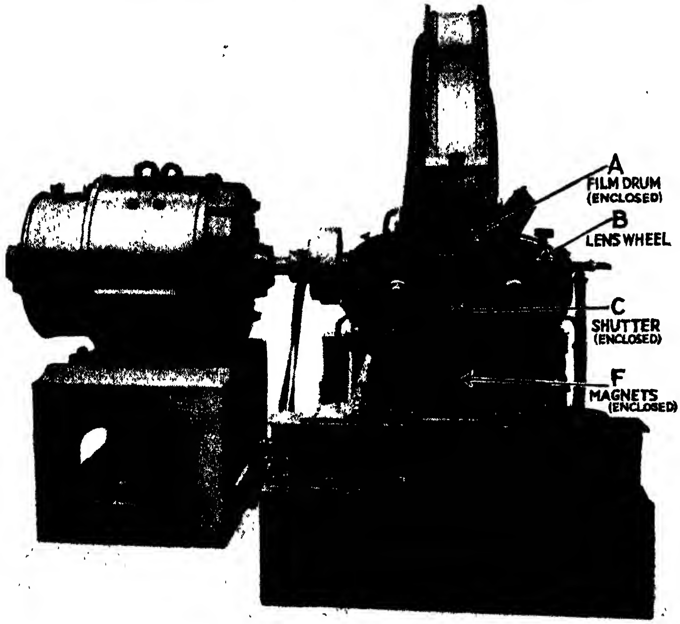


Fig. 1. Full front view with section of one of the lens wheel covers raised

of three main portions: (1) a film drum, "A" (figs. 1 and 3), on which are wound side by side two separate strips of cinema film; (2) a pair of lens wheels, one shown at "B" (figs. 1 and 3), each carrying 40 lenses, mounted on shafts geared to the film drum in such a way that the image thus cast by each lens, in turn, on the film at the optical axis moves precisely at the same speed as the film on the drum; and (3) a shutter, "C" (figs. 1, 3 and 4), to make it possible to start taking a series of photographs and to stop taking them.

Construction

Film drum

This is made of high tensile steel, 5 ft. 8 in. diameter, weighing complete with shaft 10 cwt., driven direct by an 8 h.p. electric motor, the speed of which may be varied from 100 r.p.m. to 1000 r.p.m. At the latter rate its peripheral speed is 18,000 feet per minute, causing a stress in the rim of 5 tons per square inch. Except at the point where the photographs are taken, the drum is entirely enclosed, so as to exclude light. To counteract the effect of centrifugal force and keep the films in contact with the drum, the air is exhausted

from the underside of the films by a vacuum pump connected with the film grooves through the hollow centre shaft of the drum and the pipe "D" (fig. 2). A vacuum of 25 inches of mercury (about $12\frac{1}{2}$ lb. per square inch below atmospheric pressure) is maintained. In fig. 3 only one of the grooves is shown occupied by film; note the vacuum holes in the vacant groove on film drum.

Lens Wheels

At each side of the film drum is a horizontal shaft "E" (fig. 2) mounted in ball bearings—each shaft carrying on its end a wheel of lenses—see "B" (figs. 1 and 3). These wheels are so mounted that, when they are rotated, each lens in succession throws an image on its respective film. The lens wheel shafts are driven by the drum through accurately cut bevel gearing and flexible couplings. Forty lenses are mounted in each wheel with a pitch

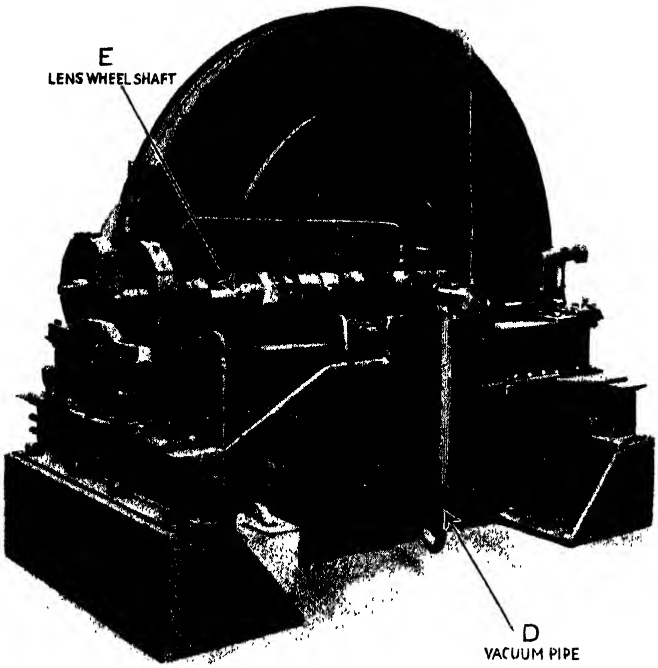


Fig. 2. Side away from motor, 45° view

corresponding to the standard pitch for cinematograph pictures, viz., 0·75 inch. The bevel gearing has a ratio of $7\frac{1}{2}$ to 1, so that the lenses pass the apertures through which the exposures are made at exactly the same rate as the film. The lenses have an aperture of F/4. Focussing is done by setting the lens wheels on their shafts by screw thread adjustments to index marks corresponding to the object distance. A range of focus of from 7′ 6″ to infinity is provided, and the angle of the field of view is: vertical 21° 14′, horizontal 26° 35′.

Shutter Mechanism

This consists mainly of a metal plate mounted vertically in grooved roller guides and arranged to drop in front of focal plane slits through which the exposures are made on the films—the plate being accelerated in its fall by strong springs. In a disk mounted on this falling plate are cut two apertures, one opposite each film. By a simple adjustment the apertures may be placed side by side if stereoscopic pictures are required or, alternatively, staggered if the two films are to be exposed in succession. The movements of the falling

plate are determined by three spring-controlled electro-magnets, "F" (figs. 1, 3 and 4), depending for their action upon an interruption in their electrical circuits. In the case of a photograph being taken of a projectile, the projectile itself would cause the first movements of the shutter by severing a wire placed in its path. The distance of this wire from the target is arranged to suit the time lag in the shutter mechanism and the speed of the projectile and is usually about 30 yards. The severing of this wire also releases the weights on the control board which determine the subsequent movements of the shutter. In the case of stereoscopic photographs the function of the shutter is to uncover the apertures to both films simultaneously and to close them after exactly one revolution of the film drum. When it is desired to expose the films consecutively the shutter can be set to uncover the aperture for each film on successive revolutions of the film drum with a slight overlap between the two sets of photographs to ensure continuity.

Control Board

This depends for its action upon the known rate of fall of weights under the influence of gravity. The two sets of falling weights are arranged to control the second and third movements of the shutter (the first movement being controlled by the severing of the wire by the projectile or other means according to the subject photographed). Electro-magnets on the control board from which are suspended the falling weights are capable of independent adjustment on vertical columns and are set to index marks graduated to correspond with film drum speeds. Each weight as it reaches the extent of its fall opens an electric circuit in which is placed the corresponding electro-magnet in the shutter mechanism. The control board is placed at a distance from the cinema machine, target and gun, to avoid interference due to concussion or earth tremor. The connecting cables are supplied 500 yards long.

Speed Indicators

These are fitted both at the motor control panel and the shutter control board. They are operated by a D.C. generator driven by the film drum, and the speed of the main motor is by the same means automatically controlled.

The House, Foundation, etc.

The cinema machine is contained in a double-walled light-tight house, access to which is obtained through an ante-chamber with double doors so that the house may be entered or left without admitting light to fog the films. A non-actinic red lamp lighted by electric accumulators is provided inside the house to enable films to be put on or taken off. Special mechanism is also provided for automatically winding the films on the drum or taking them off. The whole machine and house, including the driving motor and vacuum pump, is mounted upon a heavy steel plate provided with eyebolts for lifting chains so that it may be transported from one point to another by means of a travelling crane.

The total weight of the machine, without armour plate protection or auxiliary apparatus, is 4 tons.

Protection

In order that the machine may be suitably protected from flying splinters, etc., when photographing projectiles, the photographs are taken through a mirror which reflects the rays at right angles. The machine can then be protected by armour or sandbags, leaving only the mirror exposed. Means are provided for readily renewing the mirror in the frame when it is broken. The mirror frame is adjustable in azimuth and on a horizontal axis, and the outlook can be in any direction in one plane from horizontal to vertical. By the use of connecting cables, all the controlling apparatus, together with the electric generator, may be placed five hundred yards from the cinema machine, so that it is unnecessary for

the operator to be within the zone of danger of an explosion, although he can exercise just the same control as though he were on the spot.

Speed and Duration of Operations

At maximum speed one revolution of the film drum occupies 1/16th second, hence if the two films are exposed simultaneously (for stereoscopic vision) this is the total duration of the series of photographs at full speed. On the other hand, if one film is exposed after the other, the total for the cycle of operations will be 1/8th second. Of course, if the photographs are made at a lower rate of speed, the total duration for a series will be lengthened, and this time can be extended to 1¼ seconds when the two films are exposed consecutively. That these periods are amply long enough for the purpose is evident from the consideration of the fact that any phenomenon which requires to be photographed at such a high rate as 5000 photographs per second will be completed in a time much shorter than 1/16th of a second. For example, a shell hitting an armour plate will certainly not remain in the field of view of the machine for more than about 1/50th of a second. Similarly, supposing it is desired to photograph the action of a machine-gun firing 1000 shots per minute, a complete cycle has taken place in 1/16th of a second, and it could therefore be photographed at the full speed of the machine if desired, but a comparatively slow series of movements, such as occur in the firing of a machine-gun, would not require to be photographed as fast as 5000 photographs per second.

In practice the machine would be used at such a speed as would give the information desired, and it will be found that one complete revolution of the drum gives ample time to photograph a complete phenomenon at that rate of speed.

Illumination

Special means must be provided for illuminating the object to be photographed, for it is evident that even the strongest daylight is of no use for exposures as rapid as 1/65,000 of a second or less. To illuminate very small objects, sufficient light may be obtained from one or two powerful searchlights (say 3 ft. mirror searchlights consuming 120 amps. each); but the field which can be illuminated by such means is not more than a 15-inch diameter circle. In order to illuminate a large field, such as an armour plate, when the machine is being used at its maximum speed, the best illuminant is magnesium or aluminium, burnt under suitable conditions.

General Information

The spacing of the pictures exactly follows ordinary cinematograph practice, hence, any film taken with this machine may be projected on to the screen by means of any ordinary projector. One strip of film round the circumference of the drum contains 288 pictures.

With regard to the reproductions of slowed-down photography of high-speed phenomena next referred to, it should be noted that on account of lack of space only a limited number of exposures could be shown in connexion with this article, and the figures marked on the illustrations referred to, denoting their relative positions on the film, will indicate the gaps between them.

In the first set of pictures enlarged from photographs made by the Heape and Grylls machine one sees the progressive stages of the break up of an ordinary electric vacuum globe. It will be noticed that the side opposite to that hit by the hammer, whose fall was checked at the moment of contact, is burst by the pieces of glass broken by the hammer being hurled across by the inrush of air through the hole thus made. These flying pieces of glass puncture small holes in the globe, which gradually become bigger owing to the subsequent cracking of the globe, and through them a cloud of fine powdered glass emerges.

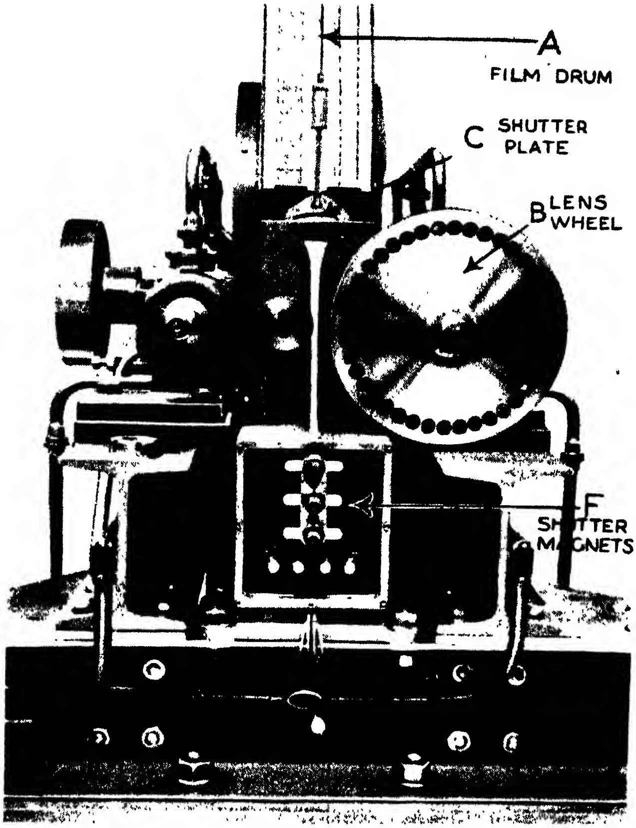


Fig. 3. Front view, one lens wheel and cover of shutter box removed and film drum cover lifted.

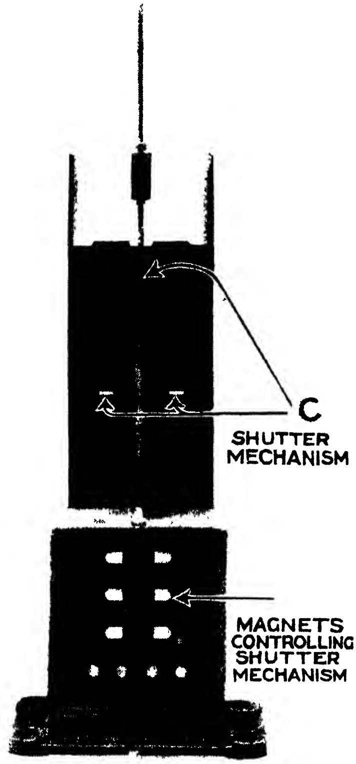
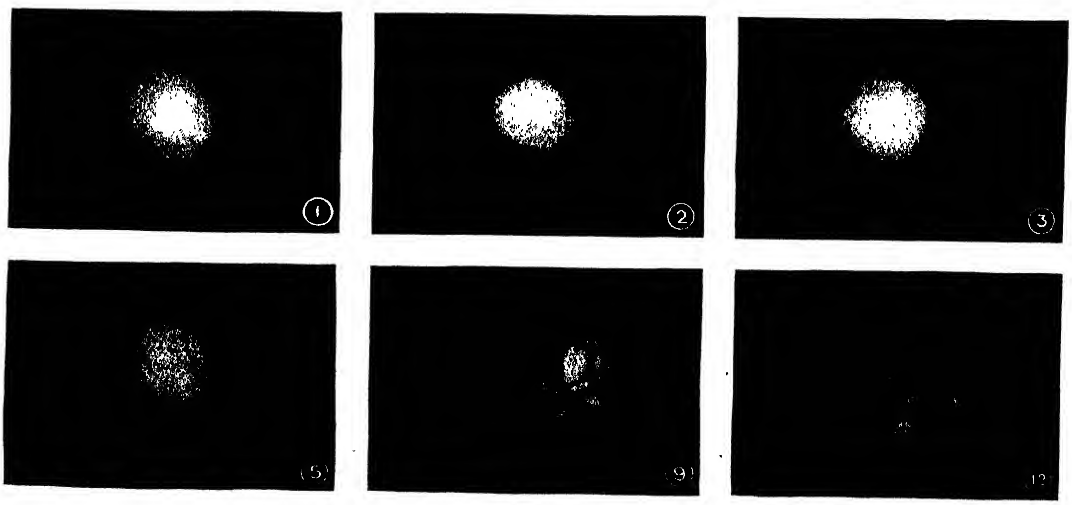


Fig. 4. Front of shutter box

Selected Photographs from Films made on the Heape-Grylls Cinema Machine

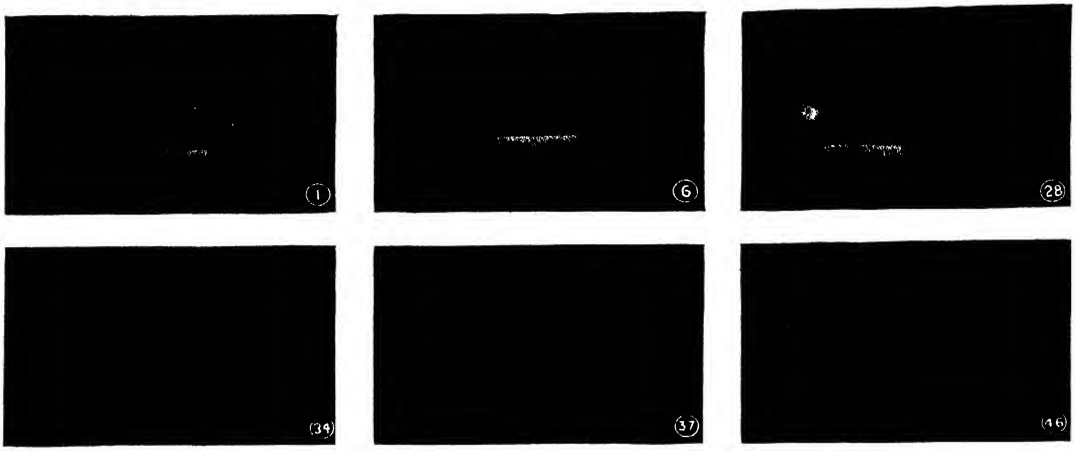
The numbers indicate the respective positions on the film of the photographs here reproduced



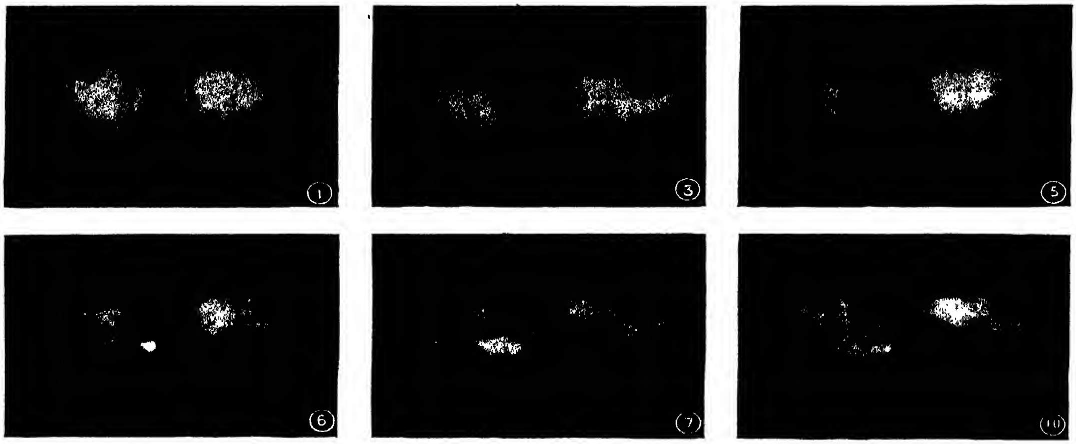
$9\frac{1}{2}$ in. vacuum globe fractured by hammer. 2500 pictures per second

Selected Photographs from Films made on the Heape-Grylls Cinema Machine

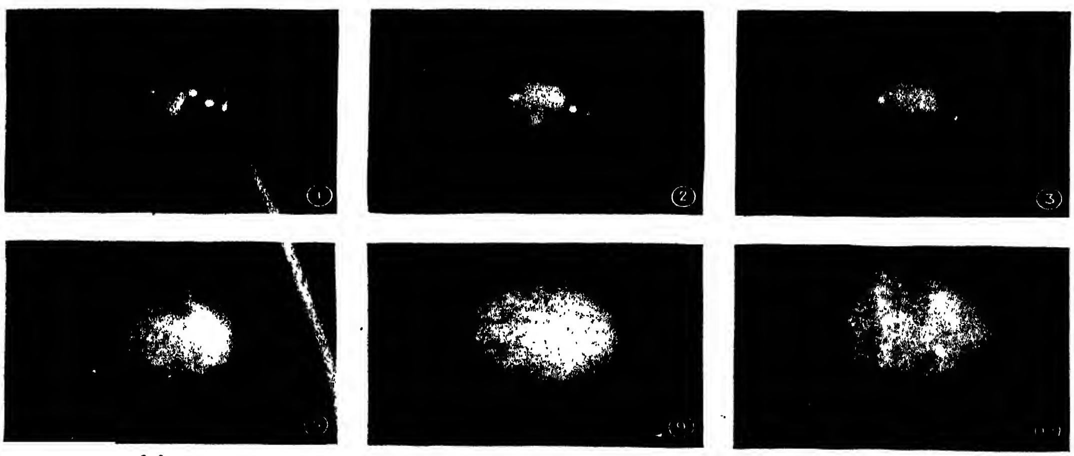
The numbers indicate the respective positions on the film of the photographs here reproduced



5 in. solid rubber ball being driven from a tee by a wooden plug fired from a gun, and rebounding from a steel target. 2000 pictures per second



5 oz. bullet, 1 in. dia., 2 in. long, being fired through a sheet of glass from rifle distant 7 ft. 6 in. Speed 1000 ft. per sec. 3000 pictures per second



9½ in. globe being exploded by smokeless powder. 2500 pictures per second

The various shapes assumed by a 5 in. solid rubber ball, weighing $2\frac{1}{4}$ lb., under the impact of a tampion fired by a small charge of gunpowder from a steel tube, and also on impact against a target, and as it recovered from these blows, are shown in the next series of pictures. In viewing the actual film it is interesting to note that the ball is struck twice in rapid succession by the wooden plug after the firing of the charge.

The third set of photographs would have been clearer had better light been possible, but the illumination available limited the exposure to 3000 pictures per second.

The fourth set of high-speed motion pictures enable one to follow in some detail the progress of the detonation of a glass globe filled with smokeless powder, itself placed inside a bigger globe, the annular space being filled with water. The flocculent appearance in No. 12 simulates that seen on the solar surface.

The above preliminary experiments indicate the wonderful possibilities of this remarkable machine, and it is hoped that in due time films will be released showing, for instance, the progressive effect of a shell ploughing its way through armour plate. The aid that such equipment should render scientists and engineers may well prove to be of great economic value, and, whichever way the subject is viewed, the Heape-Grylls machine is in truth a triumph of British applied science.

LABORATORY AND WORKSHOP NOTES

UNIFORM STRETCHING OF SMALL IRON WIRE RESISTANCE COILS BY COMBINED HEAT AND TENSION. By A. J. BEGG, Wh.Sch., B.Sc. (Eng. Hons.).

It was required so to stretch a number of small resistance coils that the heat generated, when the coils were in use, should be uniformly distributed along their length.

The following method proved both simple and effective. Each coil was suspended vertically by one end from a fixed support. The other end supported a lever carrying a scale pan. The coil was included in a circuit with a source of current, a rheostat and an ammeter and switch. For a given size of coil was found by experiment the correct combination of current and weight to stretch it to a given length. This done, each coil was coupled up and stretched in a few seconds. Small variations in the diameter of the wire were self compensating, as if there were a thin place in the coil the pitch there was automatically increased. The coils were screened from draught while stretching and the uniformity of results was very good.

The method should be applicable to other materials and to any size of coil.

ALUMINIUM PAINT IN THE LABORATORY. By B. BROWN, B.Sc.

In the laboratory or workshop we are concerned but little with appearances and so a note on a paint may appear out of place. Aluminium paint, however, possesses some very remarkable properties which render it valuable to engineer and physicist alike.

In the first place it has a higher resistance to the corrosive effects of a sulphur laden atmosphere than any other ordinary protective coating. For this reason it has been employed in structural work—not for mere appearance as is commonly thought.

In the laboratory it finds application since a surface coated with it has an extremely low radiation coefficient. Loss of heat from an oven or similar arrangement takes place chiefly by convection and radiation. If T_1 equals the temperature of the atmosphere and T_2 that of the oven, then loss by convection is roughly proportional to $T_2 - T_1$. The loss due to radiation is proportional to T_2^4. The temperatures are expressed on the absolute scale.

The advantage reaped by the use of a surface having poor radiating powers will thus be most apparent at high temperatures. Aluminium paint applied to the outer surface of ovens, especially those of the hot air type, will be found to have a remarkable effect upon the temperature obtained. With a constant gas consumption one copper oven showed a rise of 25 degrees Centigrade when coated with the paint.

Of course the actual surface temperature is increased by rendering it low in radiating power. The difference in the amount of heat emitted by a painted surface as compared with the ordinary dull metal one can be easily perceived by holding the hand at a few inches from each. It is especially to be noted that this property of aluminium painted surfaces is one so very distinct that instruments are not necessary for its appreciation.

In most instances it will not be desirable to increase the temperature of an oven or similar arrangement. If this be the case the paint should still be applied since it will effect a saving in gas and at the same time keep the temperature of the room down to more normal limits.

That the paint may be used for the inverse process of preventing heat from penetrating a cold body will be obvious from first principles. It has already a practical application in the coating of oil tanks, receptacles for the conveyance of milk, etc. Its use in the laboratory will be evident.

One more property in relation to aluminium paint and heat is of practical value. Most substances when treated with it are found to possess increased resistance to high temperatures. Actually the best results are obtained when the metal itself is applied directly by the process known as "spraying," which is becoming more popular. Nevertheless good effects are noticeable even when the metallic paint is used. The life of refractory linings is lengthened when the bricks have been so painted.

CHROMIUM ELECTROPLATING

Messrs Harcourts, Ltd. of Moseley Street, Birmingham, have sent us particulars of a process which they have recently adopted for the electrodeposition of chromium for the production of highly polished untarnishable surfaces of great hardness. The process seems to have been suggested by the value of chromium as a component of stainless steel, and to have been developed from the laboratory stage by the Metropolitan-Vickers Company, under whose patents the commercial process is being worked. The following extracts from the description received will be of interest:

"Chromium in this pure state exhibits to a greatly enhanced degree the well known stainless property and articles plated by the process need no more cleaning than similar articles made of porcelain or china. Whereas silver, copper and nickel-plate tarnish and call forth the frequent use of the thousand and one metal polishes at present on the market, chromium refuses to tarnish and requires only an occasional wash to remove accumulated dust and dirt. The deposit put down by the process is glass hard and has the appearance of highly polished silver, except that, whereas the polish of silver suggests whiteness, the polish of chromium is ever so slightly suggestive of blueness. It withstands attack from all the household acids and salts and does not tarnish in foggy or sulphurous atmospheres. The deposit being glass hard, it is not readily scratched by contact with other articles. It is a metal of very high melting point, so that relatively high temperatures leave its beautiful surface unharmed.

"A very successful application is to the bright parts of a motor-car—lamps, reflectors, handles, windscreen frames, etc., when plated by the process, withstand the rigorous conditions perfectly, and need only the usual application of the hose and sponge to bring their lustre back to original condition. Experience has shown that where a high finish is

required on non-ferrous metal parts, chromium plating is a more beautiful and more durable finish than any yet known.

"For industrial applications the process is ideal where, ordinarily, non-ferrous metal parts are installed to withstand abrasion, corrosion, erosion, or all three. One of the most severe applications is that of a valve for a filter press. A case on record shows that where manganese bronze was used, the valve had to be replaced every week. The valves of the same filter press were chromium plated and were working quite satisfactorily at the end of ten weeks of precisely similar service. From the chemical point of view, chromium is particularly resistant to sulphuric and nitric acid fumes or liquors, and troubles with non-ferrous metals, due to corrosion by these agents, will be greatly reduced, if not completely eliminated, by the use of this finish.

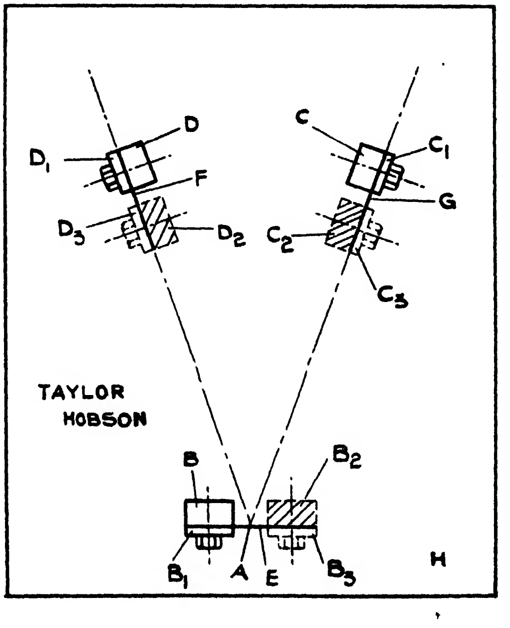
"Once the new technique is acquired, the process employed is as easy to handle as an ordinary plating process, but in the subsequent polishing process special tools and methods are adopted to deal with the glass hard material. Success with the process will depend upon training skilled men in the technique of handling the new metal.

"The principle involved is the same as any other plating process; the solutions being special, call for special methods of making up and control. The plating is conducted at a much higher current density than is usual in plating processes, and this involves the use of solid copper busbars where it is more usual to employ cable. Lead anodes, which are insoluble, are used and this is also a departure from the usual practice. It is necessary, in addition, to make special arrangements for control of temperature, and it is desirable from the point of view of health to have adequate exhaust machinery to expel all noxious fumes. It is inherently a more rapid process than the usual ones, and a coating one thousandth of an inch thick may be put down in ten minutes."

A FRICTIONLESS SUPPORT FOR SMALL OSCILLATIONS

It is sometimes required in instrument work to support an element so that it is constrained for slight rotary oscillation about an axis.

A convenient way of effecting this without introducing rubbing friction is by the use of three pieces of flat spring mounted as shown diagrammatically in plan in the accompanying illustration.



Upon a base H are three upwardly projecting lugs, B, C, D, to which respectively flat springs E, F, G are attached by screws and plates B_1, C_1, D_1. The two springs F and G lie in planes which intersect at the point A in the spring E, as shown by the dotted lines. The element to be supported by this mechanism is carried on a plate (not shown) having three dependent lugs, indicated in the diagram as B_2, C_2, D_2, and to these respectively are fastened the other ends of the flat springs by means of the screws and plates B_3, C_3, D_3. The element is then supported so that it moves only in a plane parallel to the plane of the paper, and only around the axis A.

THE TAYLOR-HOBSON RESEARCH LABORATORY, LEICESTER.

CONTEMPORARY PUBLICATIONS

The Journal of the Optical Society of America and Review of Scientific Instruments

In the September 1926 number of the above *Journal* James P. C. Southall discusses the optical theory of skiascopy or retinoscopy and comes to the conclusion that, while ordinary skiascopy provides a very useful method for determining the state of refraction of the eye the results require to be checked by other methods when a high degree of accuracy is desired. He suggests that some of the curious idiosyncrasies of vision reported by oculists may be due to the monochromatic aberrations of the eye. In a paper entitled "Spectral Filters" K. S. Gibson has compiled data which should be of value to those who wish to use filters for the ultra-violet, visible and infra-red regions of the spectrum. Special attention is given to the question of filters required for special problems such as the isolation of spectral lines and the elimination of stray light. Ludwik Silberstein presents a theoretical discussion of the collimation of light from a source of finite extension, and L. V. Foster discusses the diffraction grating and interference figure images formed by a microscope objective. Willard J. Fisher contributes a short note on aspherical lens systems. The number also contains abstracts of papers read at the Mid-winter Meeting of the Optical Society of America, and the instrument section is entirely occupied by a most valuable paper on the Einthoven String Galvanometer by H. B. Williams. This paper which occupies no less than 80 pp. is described as part 2 of a previous communication in the same *Journal* of August 1926, but it forms a remarkably complete treatise on the theory, construction and manipulation of string galvanometers, and should be read by all who are concerned with them.

Transactions of the Optical Society

In Vol. XXVII, No. 4 of these transactions. R. Kingslake describes the results of his attempts to apply the Hartmann test to the measurement of oblique primary aberrations of a lens. He claims that with ordinary precautions and care the method will yield results which are accurate to about 1 per cent. In working out the results use is made of formulae recently developed by Prof. A. E. Conrady. In the Discussion F. Robbins gives the results of measurements of Hartmann's characteristic quantity T in the case of the 26·5 inch Grubb objective at Johannesburg. In a paper entitled "Note on Chalmers' Applications of the Hartmann Test" T. Smith draws attention to the fact that in 1904 S. D. Chalmers applied the Hartmann test to the determination of all relevant aberrations of photographic lenses, thus anticipating a good deal of recent work done on this subject. He proceeds to show that the theory of such tests is readily constructed with the aid of the characteristic function.

L. C. Martin describes the results of a series of calculations on the distribution of light near the "Star focus" of a centred lens system in the cases of freedom from aberration, primary spherical aberration, and zonal spherical aberration. The characteristic extra focal effects are determined, and the effect of primary spherical aberrations on resolving power is discussed. The results obtained are an extension of those previously described by Conrady and Buxton. T. Smith suggests that the position in which the amount of energy within the first dark ring of the diffraction image of a point is a maximum not unlikely to correspond with the best focus found by visual observation in the presence of moderate amounts of aberration.

SEVENTEENTH ANNUAL EXHIBITION OF THE PHYSICAL SOCIETY AND THE OPTICAL SOCIETY

This Exhibition, which is to be held on Tuesday, Wednesday and Thursday, January 4th, 5th and 6th, 1927 at the Imperial College of Science and Technology, Imperial Institute Road, South Kensington, will be open in the afternoon (from 3 to 6 p.m.) and in the evening (from 7 to 10 p.m.).

On January 4th at 8 p.m. Professor E. N. da C. Andrade will reproduce with contemporary apparatus a Physical Lecture of the Early Eighteenth Century. On January 5th at 8 p.m. Dr C. V. Drysdale will give a lecture on "Progress in Electrical Instrument Design and Construction" and on January 6th at 8 p.m. Mr J. L. Baird will give a lecture on "Television." These lectures will be illustrated by lantern slides and experiments. Some 70 firms will exhibit scientific apparatus, and in addition there will be a group of non-commercial exhibits by Fellows of the Societies and others, including demonstrations of famous historical experiments in physics, recent research and effective lecture experiments.

It has been decided to open the Exhibition to the general public without tickets on the third day, January 6th. On January 4th and 5th tickets of admission will be required.

We understand that invitations relating to January 4th and 5th have been given to the Institution of Electrical Engineers, the Institution of Mechanical Engineers, the Chemical Society, the Radio Society of Great Britain, the Röntgen Society, the Faraday Society and other Scientific Societies. Members of such Societies should apply for tickets to the Secretary of the Society to which they belong. Others interested should apply direct to Professor A. O. Rankine, Imperial College of Science and Technology, South Kensington, S.W. 7.

TABULAR INFORMATION ON SCIENTIFIC INSTRUMENTS

XV. PYROMETERS

The table which appears overleaf contains particulars of various types of pyrometers, as furnished by their respective manufacturers. A separate copy of this table can be obtained by any reader on application to the Secretary of the Institute of Physics, 90, Great Russell Street, W.C. 1, and sets of the twelve tables published in the last volume can be supplied bound in limp cloth at 3*s*. 6*d*. per set post free.

XV. PYROMETERS

Type	Cat. No.	Range	E.M.F. in millivolts at highest temperature	Accuracy	Remarks	LIST PRICE £ s. d.
Maker:—BAIRD & TATLOCK, LTD., AND JOHN J. GRIFFIN & SONS, LTD., KEMBLE ST., KINGSWAY, W.C. 2 AND AT GLASGOW, MANCHESTER, EDINBURGH AND LIVERPOOL.						
Thermo-couple, indicating, double pivoted, wall type	2 T	0 to 100–300° C.	— 15·5	— ± 5° C.	— Cu-con. couples	12 10 0
Do. lab. type	14 T		—	—	—	12 10 0
Do. portable type	8 T	0 to 400–800° C.	45·5	± 5° C.	Fe-con. couples	13 10 0
Thermo-couple, recording, double pivot, single point, drum	X 3440	0 to 750–1250° C.	50·5	± 8° C.	Chromel-alumel couples	35 0 0
Do. four point, continuous	X 3446	0 to 1000–1500° C.	17·5	± 5° C.	Pt.-pt. rhodium couples	70 0 0
Do. six point, continuous	X 3448	—	—	—	—	80 0 0
Thermo-couple, totally suspended, indicators and recorders as above	—	As above	—	As above	Sensitivities about twice those of pivoted movements	As above
Resistance, indicators and recorders as above	—	− 150 to + 150° C.	—	0·5° C.	—	On application
Maker:—BOWEN INSTRUMENT CO., 9 NEWTON ROAD, LEEDS.						
Thermo-couple: base-metal type	—	0–400° C.	20–25	± 1% full scale	High resistance	From 8 10 0
" "	—	0–1300° C.	Max. 90	"	Medium resistance	" 14 0 0
Do. rare-metal type	—	0–1400° C.	14·5	"	High resistance	" 18 0 0
Resistance	—	− 20 to + 550° C.	—	± ½%	Direct reading. Indep. of battery voltage. Current used about 0·05 amp.	" 20 0 0
Total radiation	—	500 to 2000° C.	70	± 1 to 2%	Fixed focus. No manipulation	" 18 0 0
Wanner simplex optical	-	640 to 4000° C.	—	± 1%	Polarizing type. Portable outfit	" 25 0 0
Maker:—CAMBRIDGE INSTRUMENT COMPANY, LTD., 45 GROSVENOR PLACE, WESTMINSTER, S.W. 1.						
Resistance thermometers	11411	Up to 1200° C.	—	—	Commercial pattern in porcelain or quartz tube, enclosed head, with open-ended removable steel sheath and stop flange	11 0 0 to 46 0 0 for lengths from 12 to 66 inches
"	11412	Up to 500° C.	—	—	Steel tube pattern, with adjustable stop flange, with silver leads suitable for temperatures not exceeding 500° C.	4 0 0 to 5 10 0 for lengths from 12 to 60 inches
"	11413	"	—	—	Porcelain tube pattern with platinum leads	10 15 0 to 41 15 0 for lengths from 12 to 60 inches
"	11414	"	—	—	Laboratory pattern in porcelain or quartz tube, with silver leads suitable for temperatures not exceeding 500° C.	12″ 5 10 0
"	11415	"	—	—	Ditto, with platinum leads	12″ 11 5 0
"	11416	"	—	- -	Blast furnace pattern in porcelain tube with removable steel sheath, flanged socket, screwed 1½″ gas thread and cover	11″ 12 15 0 13″ 14 0 0 15″ 15 5 0 17″ 16 10 0
Indicators for above:						
Whipple temperature indicator	11151	− 10 to + 1200° C.	—	± 1° C.	Graduated every degree. Complete in teak case	31 10 0
Callendar recorder with 100 charts	11311	"	—	—	—	75 0 0
Callendar recorder with range of 100° C. or 200° C. across scale and switchboard to give zero value in steps of 50° C. complete with 100 standard charts	11312	"	—	—	—	80 0 0
Thermo-couples:						
Platinum, platinum-rhodium	12461	1400° C.	—	—	Commercial pattern in quartz tube, enclosed head, with outer removable open-ended steel sheath and adjustable stop flange	12″ 6 10 0 18″ 9 0 0 24″ 11 10 0 30″ 14 5 0 36″ 17 0 0 42″ 20 0 0
"	12463	"	—	—	Ditto, in quartz tube, enclosed head, with outer fire-clay sheath and socket	48″ 23 0 0 54″ 26 0 0 60″ 29 0 0
"	12467	"	—	—	Small muffle pattern in quartz tube, enclosed head, with small diameter open-ended outer steel sheath and adjustable stop flange	12″ 6 10 0
"	12466	"	—	—	Laboratory pattern in porcelain or quartz tube	12″ 6 10 0
Titan thermo-couples	12471	1200° C.	—	—	Commercial pattern in quartz tube, enclosed head, with outer removable open-ended steel sheath and adjustable stop flange	12″ 2 0 0 18″ 2 10 0 24″ 3 0 0 30″ 3 10 0 36″ 4 0 0

Type	Cat. No.	Range	E.M.F. in millivolts at highest temperature	Accuracy	Remarks	LIST PRICE
Maker:—CAMBRIDGE INSTRUMENT COMPANY, LTD., 45 GROSVENOR PLACE, WESTMINSTER, S.W. 1.						£ s. d.
Titan thermo-couples	12473	1200° C.	—	—	Commercial pattern in quartz tube, enclosed head, with outer fire-clay sheath and socket	42″ 4 10 0 48″ 5 0 0 54″ 5 10 0 60″ 6 0 0 66″ 6 10 0
"	12477	"	—	—	Molten metal pattern, consisting of chromel-alumel wires covered with special cement, fitted with handle and hand shield	48″ 4 0 0
Iron constantan thermo-couples	12432	Up to 600° C.	—	—	Plain stem pattern in steel tube, with enclosed head and adjustable stop flange (for temperatures to 800° C. 2*s.* per foot extra)	12″ 1 10 0 24″ 1 12 6 36″ 1 15 0
"	12436	Up to 800° C.	—		Screwed pattern in steel tube, with enclosed head and collar screwed ⅜″ gas	Up to 12″ 1 15 0
"	12437	"	—	—	Molten metal pattern, consisting of asbestos covered wires, with handle and hand shield (for temperatures to 800° C.)	48″ 3 3 0
"	12493	"	—	—	Contact pattern	5 5 0
Indicators for above:						
Portable, pivoted	12111	Up to 1400° C.	—	—	—	12 10 0
Totally suspended	12151	"	—	—	High resistance. Millivolt scale	16 10 0
Wall pattern, pivoted	12211	"	—	—	Standard pattern 7″ scale with bracket	12 10 0
"	12231	Up to 1200° C.	—	-	Small pattern 4½″ scale (for base-metal thermo-couples only)	10 0 0
Totally suspended	12251	Up to 1400° C.	—	—	High resistance. Millivolt scale	16 10 0
Totally enclosed	12261	—	—	—	In dust and fume-tight metal case with switch for 6 points	22 0 0 £3 for each additional 6 points
Thread recorder. 100 standard 24-hour charts. 1 record on chart	12351	—	—		In dust and fume-tight metal case	42 0 0
Ditto, fitted with 2-colour mechanism giving 2 records on chart	12352	—	-	—	"	52 0 0
Ditto, with 3-colour mechanism giving 3 records on chart	12353	—	—	-	"	62 0 0
Ditto, with 100 standard 24-hour charts. 2-colour mechanism giving four records on one chart of double width	12355	—	—	—	"	75 0 0
Ditto, 3-colour mechanism giving 6 records on a chart	12356	-	—	-	"	87 0 0
Radiation and optical pyrometers:						
Thermo-couple, resistance, total radiation						
Féry radiation pyrometer. Portable indicating outfit	13111	500–1100° C. 600–1400° C. 800–1700° C.	3·4 7·0 13·0	± 10° C. up to 1300° C.	Féry telescopes. Open fronted	†27 0 0
Ditto. Simple fixed indicating outfit	13121	600–1200° C. 700–1400 C. 900–1700° C.	2·7 4·0 8·0	"	Féry telescopes, enclosed with glass front. Multi-point outfits supplied	27 15 0
Ditto. Simple recording outfit	13131	600–1200° C. 700–1400° C. 900–1700° C.	2·7 4·0 8·0	"	See note above	57 15 0
Optical pyrometer	13614	700–1400° C.	—	± 10° C. to 1400° C.	Sub-standard instrument. Self-checking portable. Can be sighted on small objects and is easily operated	*37 0 0
Optical pyrometer	13620	900–2000° C.	—	± 10° C. to 1400° C. ± 15° C. to 1600° C. ± 20° C. above 1600° C.	" "	*37 0 0
Optical pyrometer, double range	13624	700–1400° C. 900–2000° C.	—	± 10° C. up to 1400° C. ± 15° C. up to 1600° C.	" "	*42 0 0
Ditto, double range	13625	700–1400° C. 1200–2500° C.	—	"	" "	*42 0 0
Ditto, double range	13640	900–2000° C. 1400–4000° C.	—	"	" "	*45 0 0
Disappearing filament pyrometer	13411	700–1400° C. 900–1600° C.	—	± 15° C. up to 1600° C.	A simple inexpensive instrument	24 0 0
Ditto, double range	13421	700–1300° C. 1000–2100° C.	—	± 15° C. to 1300° C. ± 30° C. to 2100° C.	See note above	27 10 0
Disappearing filament pyrometer. Sub-standard type		700–1550° C.	·316 amps at 700° C. ·529 amps at 1550° C.	± 5° C. at 1550° C.	Sub-standard instrument for use with a potentiometer	†75 0 0
		1300–2300° C.	·35 amps at 1300° C. ·525 amps at 2300° C.	± 7° C. at 1300° C. ± 20° C. at 2300° C.		

* Including N. P. L. Certificate. † N. P. L. Certificate extra at cost.

Type	Cat. No.	Range	E.M.F. in millivolts at highest temperature	Accuracy	Remarks	LIST PRICE £ s. d.
Maker:—FOSTER INSTRUMENT Co., LETCHWORTH, HERTS.						
Thermo-couple, rare-metal, wall type indicating, edgewise scale, metal case with swivel bracket: "Resilia" mounting	6120	0–1100° C.	12	± 1% of max. or to requirements	10" scale, with anti-parallax mirror: magnetically shielded: can be supplied with magnifier at slight extra cost	19 0 0
	6420	0–1400° C.	16			19 0 0
Ditto, but without swivel bracket: "Resilia" mounting	6120 d	0–1100° C.	12	,,	5" scale: magnetically shielded	13 0 0
	6420 d	0–1400° C.	16	,,	,, ,,	13 0 0
Thermo-couple, rare-metal, portable indicating, in hardwood case: "Resilia" mounting	6150	0–1100° C.	12	,,	7" scale, with anti-parallax mirror	14 0 0
	6450	0–1400° C.	16	,,	,, ,,	14 0 0
Thermo-couple, rare-metal, recording, "Strip" pattern: "Resilia" mounting	6180 s	0–1100° C.	12	,,	Cast-iron case: magnetically shielded: complete with chart roll	55 0 0
	6480 s	0–1400° C.	16	,,		55 0 0
Thermo-couple, base-metal, wall type indicating, circular metal case: "Resilia" mounting	230	0 200° C.	10	,,	5" scale: magnetically shielded	11 10 0
	430	0–400° C.	21	,,	,, ,,	11 10 0
	730	0–650° C.	35	,,	,, ,,	11 10 0
	930	0–900° C.	50	,,	,, ,,	11 10 0
	1130	0–1050° C.	60	,,	,, ,,	11 10 0
	1334	0–1300° C.	50	,,	,, ,,	11 10 0
Thermo-couple, base-metal, wall type indicating, edgewise metal case: "Resilia" mounting	230 d	0–200° C.	10	,,	5" scale: magnetically shielded	13 0 0
	430 d	0–400° C.	21	,,	,, ,,	13 0 0
	730 d	0–650° C.	35	,,	,, ,,	13 0 0
	930 d	0–900° C.	50	,,	,, ,,	13 0 0
	1130 d	0–1050° C.	60	,,	,, ,,	13 0 0
	1334 d	0–1300 C.	50	,,	,, ,,	13 0 0
Thermo-couple, base-metal, wall type indicating, edgewise metal case with swivel bracket: "Resilia" mounting	230 y	0–200° C.	10	,,	10" scale, with anti-parallax mirror: magnetically shielded. Magnifier can be supplied	19 0 0
	430 y	0–400° C.	21	,,		19 0 0
	730 y	0–650° C.	35	,,		19 0 0
	930 y	0–900° C.	50	,,	,, ,,	19 0 0
	1130 y	0–1050° C.	60	,,	,, ,,	19 0 0
	1334 y	0–1300° C.	50	,,	,, ,,	19 0 0
Thermo-couple, base-metal, portable indicating, hardwood case: "Resilia" mounting	250	0–200° C.	10	,,	5" scale	12 0 0
	450	0–400° C.	21	,,	,,	12 0 0
	750	0–650° C.	35	,,	,,	12 0 0
	950	0–900° C.	50	,,	,,	12 0 0
	1150	0–1050 C.	60	,,	,,	12 0 0
	1354	0–1300° C.	50	,,	,,	12 0 0
Thermo-couple, base-metal, portable indicating, hardwood case: "Resilia" mounting	250 Y	0–200° C.	10	,,	7" scale	14 0 0
	450 Y	0–400° C.	21	,,	,,	14 0 0
	750 Y	0–650° C.	35	,,	,,	14 0 0
	950 Y	0–900° C.	50	,,	,,	14 0 0
	1150 Y	0 1050° C.	60	,,	,,	14 0 0
	1354 Y	0–1300° C.	50	,,	,,	14 0 0
Thermo-couple, base-metal, recording: ink pattern in hardwood case; 24-hour disc chart: "Resilia" mounting	280	0 200° C.	10	,,	10" dia. chart. Complete with 100 charts	36 15 0
	480	0–400° C.	21	,,	,, ,,	36 15 0
	780	0–650° C.	35	,,	,, ,,	36 15 0
	980	0–900° C.	50	,,	,, ,,	36 15 0
	1180	0–1050° C.	60	,,	,, ,,	36 15 0
	1384	0–1300° C.	50	,,	,, ,,	36 15 0
Thermo-couple, base-metal, recording: dial pattern in cast-iron case: 24-hour disc chart: "Resilia" mounting	280 d	0–200° C.	10	,,	Magnetically shielded. Supplied with 100 charts	26 0 0
	480 d	0–400° C.	21	,,		26 0 0
	780 d	0–650° C.	35	,,	,, ,,	26 0 0
	980 d	0–900° C.	50	,,	,, ,,	26 0 0
	1180 d	0–1050 C.	60	,,	,, ,,	26 0 0
	1384 d	0–1300 C.	50	,,	,, ,,	26 0 0
Thermo-couple, base-metal, recording: strip pattern in cast-iron case; continuous chart: "Resilia" mounting	280 s	0–200 C.	10	,,	Magnetically shielded. Supplied with chart roll for 30 days	55 0 0
	480 s	0–400 C.	21	,,		55 0 0
	780 s	0–650 C.	35	,,	,, ,,	55 0 0
	980 s	0–900 C.	50	,,	,, ,,	55 0 0
	1180 s	0–1050° C.	60	,,	,, ,,	55 0 0
	1384 s	0–1300° C.	50	,,	,, ,,	55 0 0

NOTE: the strip pattern recorder can be supplied to give multiple records up to six. Prices on application.

Type	Cat. No.	Range	E.M.F. in millivolts at highest temperature	Accuracy	Remarks	LIST PRICE £ s. d.
Resistance, wall type indicating: self-compensating Wheatstone Bridge: circular metal case	030	− 10 110° C.	--	1% of max. or to requirements	5" scale: magnetically shielded	13 10 0
	130	80 200° C.	--		,, ,,	13 10 0
	330	120–360° C.	--	,,	,, ,,	13 10 0
Ditto, edgewise metal case	030 d	− 10 110° C.	—	,,	5" scale ,,	15 0 0
	130 d	80–200° C.	—	,,	,, ,,	15 0 0
	330 d	120–360 C.	—	,,	,, ,,	15 0 0
Ditto: edgewise metal case with swivel bracket	030 y	− 10–110° C.	—	,,	10" scale, with anti-parallax mirror: magnetically shielded	21 0 0
	130 y	80–200° C.	—	,,		21 0 0
	330 y	120–360 C.	—	,,	,, ,,	21 0 0
Resistance, recording: self-compensating Wheatstone Bridge: ink pattern in hardwood case, with disc chart (24-hour)	080	− 10–110 C.	---	,,	With 100 charts. 10" dia. charts	42 15 0
	180	80–200° C.	---	,,	,, ,,	42 15 0
	380	120–360 C.	--	,,	,, ,,	42 15 0
Ditto: dial pattern in cast-iron case, with 24-hour disc chart	080 d	− 10–110° C.	-	,,	With 100 charts. 10" dia. charts: magnetically shielded	29 0 0
	180 d	80–200° C.	—	,,		29 0 0
	380 d	120–360° C.	—	,,	,, ,,	29 0 0
Ditto: strip pattern in cast-iron case	080 s	− 10–110° C.	-	,,	With chart roll for 30 days: magnetically shielded	55 0 0
	180 s	80–200° C.	—	,,		55 0 0
	380 s	120–360° C.	—	,,	,, ,,	55 0 0
Total radiation, wall type indicating: circular metal case: "Resilia" mounting	1033	500–1000° C.	--	2% of max. or to requirements	5" scale: magnetically shielded	13 10 0
	1433	700–1400° C.	- -		,, ,,	13 10 0
	1633	800–1600° C.	–	,,	,, ,,	13 10 0
	1833	900–1800° C.	—	,,	,, ,,	13 10 0
Ditto: edgewise metal case	1033 d	500–1000° C.	—	,,	5" scale ,,	15 0 0
	1433 d	700–1400° C.	—	,,	,, ,,	15 0 0
	1633 d	800–1600° C.	—	,,	,, ,,	15 0 0
	1833 d	900–1800° C.	—	,,	,, ,,	15 0 0

Maker:—FOSTER INSTRUMENT Co., LETCHWORTH, HERTS.

Type	Cat. No.	Range	E.M.F. in millivolts at highest temperature	Accuracy	Remarks	LIST PRICE £	s.	d.
Total radiation, wall type indicating: edgewise metal case with swivel bracket	1033 y	500–1000° C.	—	2 % of max. or to requirements	10″ scale, with anti-parallax mirror: magnetically shielded	21	0	0
	1433 y	700–1400° C.	—			21	0	0
	1633 y	800–1600° C.	—	,,	,, ,,	21	0	0
	1833 y	900–1800° C.	—	,,	,, ,,	21	0	0
Total radiation, portable indicating: simple pattern in hardwood case: "Resilia" mounting	1053	500–1000° C.	—	,,	5″ scale	14	0	0
	1453	700–1400° C.	—	,,	,,	14	0	0
	1653	800–1600° C.	—	,,	,,	14	0	0
	1853	900–1800° C.	—	,,	,,	14	0	0
Total radiation, portable indicating: in hardwood case: "Resilia" mounting	1053 Y	500–1000° C.	—	,,	7″ scale	16	0	0
	1453 Y	700–1400° C.	—	,,	,,	16	0	0
	1653 Y	800–1600° C.	—	,,	,,	16	0	0
	1853 Y	900–1800° C.	—	,,	,,	16	0	0
Total radiation, recording: ink pattern in hardwood case: 24-hour disc chart: "Resilia" mounting	1083	500–1000° C.	—	,,	10″ dia. charts. Complete with 100 charts	38	15	0
	1483	700–1400° C.	—	,,		38	15	0
	1683	800–1600° C.	—	,,	,, ,,	38	15	0
	1883	900–1800° C.	—	,,	,, ,,	38	15	0
Total radiation, recording: dial pattern in cast-iron case: 24-hour disc chart: "Resilia" mounting	1083 d	500–1000° C.	—	,,	Magnetically shielded. 100 charts supplied	28	0	0
	1483 d	700–1400° C.	—	,,		28	0	0
	1683 d	800–1600° C.	—	,,	,, ,,	28	0	0
	1883 d	900–1800° C.	—	,,	,, ,,	28	0	0
Total radiation, recording: strip pattern in cast-iron case: continuous chart: "Resilia" mounting	1083 s	500–1000° C.	—	,,	Magnetically shielded. Supplied with chart roll for 30 days	57	0	0
	1483 s	700–1400° C.	—	,,		57	0	0
	1683 s	800–1600° C.	—	,,	,, ,,	57	0	0
	1883 s	900–1800° C.	—	,,	,, ,,	57	0	0
Optical pyrometer complete: "Lamp Bridge Unit" pattern: with carrying case	2260	700–1200° C.	—	1 % of max. or to requirements	Complete outfit, with battery	28	0	0
	2560	900–1450° C.	—		,, ,,	28	0	0
	2760	800–1700° C.	—	,,	,, ,,	29	0	0
	2960	1250–2250° C.	—	,,	,, ,,	29	0	0
	2270/1950	700–1200° C. and 900–1950° C.	—	,,	,, ,,	32	0	0
	2570/2250	900–1450° C. and 1250–2250° C.	—	,,	,, ,,	32	0	0
	2290/1450	1200–700° C. and 1200–1450° C.	—	,,	Do. Reversing scale	30	0	0
Optical pyrometer complete: simple circuit pattern: with carrying case	2465	800–1400° C.	—	2 % of max. or to requirements	Complete outfit, with battery	23	10	0
	2865	1000–1800° C.	—		,, ,,	24	10	0

Maker: —R. F. HAMILTON & Co., LTD., 25 SPRING ROAD, EDGBASTON, BIRMINGHAM.

These pyrometers are always made to order and calibrated as required. The particulars below are from instruments just sent out:

Type	Cat. No.	Range	E.M.F. in millivolts at highest temperature	Accuracy	Remarks
Indicator / Recorder } thermo-electric	—	0–1000° C. or 0–1400° C.	24·04 mv. or 14·12 mv.	± 1° C.	Suspensions of patented unbreakable form. Compensated for temperature variation and if required the cold junction can also be compensated without using compensating leads

Maker:—MESSRS NEGRETTI & ZAMBRA, 38 HOLBORN VIADUCT, E.C. 1.

Type	Cat. No.	Range	E.M.F. in millivolts at highest temperature	Accuracy	Remarks	£	s.	d.
Resistance indicator, totally enclosed with switch gear for 6 pts	RT/6	– 50 to 250° C.	—	± ¼%	Lever switches	32	0	0
Ditto: 12 points	RT/12	,,	—	,,	,,	41	0	0
Ditto: 24 points	RT/24	,,	—	,,	,,	53	0	0
Resistance element for air-temperatures	B/110	,,	—	,,	—	1	15	0
Ditto for pipes, etc.	B/101	,,	—	,,	—	2	0	0
Thermo-couple indicator, totally enclosed, 6 points	NC/6	0–1000° C.	31·6 mv.	± 1%	Rotary switch	21	0	0
	BM/6	0–800° C.	29·4 mv.	,,	,,	21	0	0
	RM/6	0–1500° C.	17·5 mv.	± ½%	,,	21	0	0
Ditto with switch gear for 12 pts	—	—	—	—	,,	26	0	0
Ditto with switch gear for 24 pts	—	—	—	—	,,	32	0	0
Base-metal thermo-couple for flue gas, etc. 3 ft. long	B/113	0–800° C.	29·4 mv.	± 1%	Steel tube	2	0	0
Base-metal thermo-couple for furnaces, etc. 3 ft. long	B/117	0–1000° C.	31·6 mv.	,,	Silica tube	3	7	0
Rare-metal thermo-couple for furnaces, etc. 2 ft. long	B/122	0–1500° C.	17·5 mv.	± ½%	Alundum tube	10	10	0
Thermo-couple indicator in portable teak case	P.T.	,,	,,	,,	With "cold end" thermometer	13	0	0
Rare-metal thermo-couple for laboratory, etc. 1 foot long	B/124	,,	,,	,,	Alundum tube	5	10	0

Maker:—SARCO ENGINEERING & TRADING Co., LTD., ALDWYCH HOUSE, W.C. 2.

Type	Cat. No.	Range	E.M.F. in millivolts at highest temperature	Accuracy	Remarks		£	s.	d.
Thermo-couple:									
Base-metal type	—	0–400° C.	20–25	± 1% full scale	High resistance	From	8	10	0
Ditto	—	0–1300° C.	Max. 90	,,	Medium resistance	,,	14	0	0
Rare-metal type	—	0–1400° C.	14·5	,,	High resistance	,,	18	0	0
Resistance	—	– 20 to + 550° C.	—	± ½%	Direct reading. Independent of battery voltage; current used about 0·05 amp.	,,	20	0	0
Total radiation	—	500 to 2000° C.	70	± 1 to 2%	Fixed focus, no manipulation	,,	18	0	0
Wanner simplex optical	—	640 to 4000° C.	—	± 1%	Polarizing type portable outfit	,,	25	0	0

Type	Cat. No	Range	E.M.F. in millivolts at highest temperature	Accuracy	Remarks	LIST PRICE
Maker:—MESSRS SIEMENS BROS. & CO., LTD., WOOLWICH, S.E. 18.						
Indicators:					Resistance:	£ s. d
Suspended coil type (5½" scale)	P. 4000	These instruments may be calibrated for direct connection to thermo-couples or may be used in conjunction with a bridge and resistance thermometers. In either case the range will depend on the couple or thermometer with which they are to be used	—	± 1%	45 ohms per millivolt	13 0 0
Pivoted portable type (5½" scale)	P. 4010		—	"	15 "	12 10 0
" wall type (4½" scale)	P. 4020		—	"	15 "	12 10 0
" " (10" scale)	P. 4030		—	"	12 "	15 0 0
" portable type (4½" scale)	P. 4100*		—	"	1·5 "	10 0 0
" wall type (4½" scale)	P. 4110*		—	"	1·5 "	10 0 0
Recorders:						
Drum type (24 hour chart)	P. 2601†		—	"	10 "	22 10 0
Continuous paper type (2 months chart supply)	P. 2501†		—	"	45 "	45 0 0

* Not suitable for use with rare-metal couples. † Useful width of chart: P. 2601, 3⅞"; P. 2501, 4⅞".

Type	Cat. No	Range	E.M.F. in millivolts at highest temperature	Accuracy	Remarks	LIST PRICE
Thermo-couples:						
Copper constantan (1·5 mm. dia. wire)	—	Up to 500° C.	25 approx.	± 5° C.	Prices are per foot for thermo-couples only without insulators	2 0
Iron constantan (1·5 mm. and 3 mm. dia. wire)	P. 3470 and P. 3480	" 800° C.	45 "	"	" "	2 0
Alchro (3 mm. dia. wire)	P. 3270	" 1000° C.	40 "	"	" "	7 6
Platinum, platinum rhodium (0·5 mm. dia. wire)	P. 3170	" 1400° C.	15 "	"	" "	3 10 0
Resistance thermometers:						
Nickel wire coils	P. 5501	200° C. to 100° C.	—	± 0·5° C.		1 15 0
Platinum wire coils	P. 5521	0 to 500° C.	—	± 1° C.	—	2 5 0
Optical pyrometers:						
Disappearing filament type	P. 7000	700 to 1400° C. 1400° to 2400 C. (with absorption screen)	—	± 10° C.	Price for complete outfit	27 10 0
Water pyrometer:						
With copper or iron cylinders	P. 1500 or P. 1510	0-1000 C.	—	—	—	6 0 0
With nickel cylinders	P. 1520	0–1200° C.	—	—		6 0 0

We regret that owing to an oversight the Foster Instrument Company were not invited to give particulars of their Permanent Magnet Laboratory Voltmeters and Ammeters for Table No. XII which appeared in the September issue and we therefore reproduce below a table which they have kindly furnished us of their types of Moving Coil Instruments.

List No.	Description	Dimensions: Pointer length mm.	Dimensions: Scale length mm.	Dimensions: External cm.	Range	No. of scale divs.	Res. ohms	Accuracy % of max.	Periodic time secs.	Damping	Remarks	LIST PRICE £ s. d.
Maker:—FOSTER INSTRUMENT CO., LETCHWORTH, HERTS.												
3240y/120	Moving coil permanent magnet microammeter: "Resilia" double pivot mounting, wall type edgewise with swivel bracket	180	260	28 27 7·5	120 ma.	240	700	*	—	Magnetic	Fully magnetically shielded. Magnifier can be supplied at extra price	23 10 0
3040y/120	Ditto, but wound and calibrated as a millivoltmeter	180	260	28 27 7·5	120 mv.	240	5	*	—	"	" "	23 10 0
3240d/120	Moving coil permanent magnet microammeter: "Resilia" double pivot mounting, edgewise for rigid wall fixing	120	130	17 16 8	120 ma.	120	700	*	—	"	Fully magnetically shielded	17 10 0
3040d/120	Ditto, but wound and calibrated as a millivoltmeter	120	130	17 16 8	120 mv.	120	5	*	—	"	" "	17 10 0
3240M/240	Moving coil permanent magnet microammeter: "Resilia" double pivot mounting; miniature instrument	34	70	8·5 dia. 3·7	240 ma.	48	300	1·0	0·5	"	" "	5 15 0
3040M/120	Ditto, but wound and calibrated as a millivoltmeter	34	70	8·5 dia. 3·7	120 mv.	60	5	"	"	"	" "	5 15 0
3250/240	Moving coil permanent magnet microammeter: "Resilia" double pivot mounting, portable in polished hardwood case	90	130	19 19 8	240 ma.	120	500	"	1·0	"	Ditto, simple, specially robust instrument	14 0 0
3050/120	Ditto, but wound and calibrated as a millivoltmeter	90	130	19 19 8	120 mv.	120	5	"	"	"	" "	14 0 0
3260/120	Moving coil permanent magnet microammeter, portable in polished hardwood case with lid: "Resilia" double pivot mounting	130	180	25 23 10·5	120 ma.	120	700	*	—	"	Fully magnetically shielded. High precision instrument	25 0 0
3070/120	Ditto, but wound and calibrated as a millivoltmeter	130	180	25 23 10·5	120 mv.	120	5	*	—	"	" "	25 0 0
3170	Ditto, multi-range millivoltmeter	130	180	25 23 10·5	12, 24, 60, 120 mv.	120	—	*	—	"	Fully magnetically shielded	31 0 0

* To British Engineering Standards Association specification for sub-standard instruments.

Instruments generally similar to the microammeters are supplied calibrated as voltmeters, and the millivoltmeters as ammeters. Prices, varying according to range, on application.

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A METHOD OF COMPARING THE THERMAL CONDUCTIVITIES OF METAL RODS.

By PROF. GEORGE W. TODD, M.A., D.Sc., F.INST.P. Armstrong College, University of Durham.

[*MS. received, 7th November*, 1926.]

It is usual to compare the thermal conductivities of metal rods by either the Ingen-Hausz method or the Despretz method. Neither is free from objection. In the first method, unless a fairly high temperature is maintained at the ends of the rods, the distances to which the wax melts for low conductivity metals are too small for accurate comparisons to be made. The main objection to the second method is probable modifications produced in the heat flow at thermometer holes or thermoelectric contacts, especially if the rods are of small cross-section.

The method to be described suffers from none of these objections, since temperatures are not measured and the uncertainties introduced by assuming a constant emissivity at different temperatures can be reduced to a minimum by using much smaller temperature differences than are possible in the other methods. Although the method is so obvious, the writer is unaware of its having been previously suggested or used.

Theory. For steady flow in a long bar heated at one end, the difference between the heat entering one face of a section dx and the heat leaving the other face is equal to the heat leaving the surface of the element, i.e.

$$KA\frac{d^2\theta}{dx^2} = \epsilon p\theta,$$

where

K = thermal conductivity,
θ = temp. excess over air temp.,
A = area of cross-section,
p = perimeter of cross-section,
ϵ = surface emissivity.

Putting $\mu^2 = \frac{\epsilon p}{KA}$, the solution may be written

$$\theta = Me^{\mu x} + Ne^{-\mu x},$$

M and N being constants depending on the conditions of the experiment.

If we maintain one end ($x = 0$) of the bar at a constant temperature excess (θ_0) above the air temperature and the bar is sufficiently long for the other end to be at air temperature, then $M = 0$ and $N = \theta_0$. So that the temperature excess at any distance x is given by

$$\theta = \theta_0 e^{-\mu x}.$$

Now the expansion of length dx at a distance x from the heated end of the bar will be $\alpha.\theta.dx$, α being the coefficient of expansion. The expansion of a length l is therefore

$$E = \alpha\theta_0\int_0^l e^{-\mu x}.dx = \frac{\alpha\theta_0}{\mu}(1 - e^{-\mu l}).$$

Since l is taken great enough for there to be no excess temperature at the remote end of the rod, we have

$$E = \frac{\alpha\theta_0}{\mu}.$$

Comparing the expansions of two rods projecting from the same heater gives

$$\frac{E_1}{E_2} = \frac{\alpha_1\mu_2}{\alpha_2\mu_1}$$

or,

$$\left(\frac{E_1\alpha_2}{E_2\alpha_1}\right)^2 = \frac{\epsilon_2 p_2 K_1 A_1}{\epsilon_1 p_1 K_2 A_2} \qquad \ldots\ldots(1).$$

For rods of circular cross-section and equal surface emissivity the expression reduces to

$$\frac{K_1}{K_2} = \frac{d_2}{d_1}\left(\frac{E_1\alpha_2}{E_2\alpha_1}\right)^2 \qquad \ldots\ldots(2),$$

d denoting diameter.

By using rods of the same metal with equal cross-sections, the emissivities of different coatings may be compared, for

$$\frac{\epsilon_2}{\epsilon_1} = \left(\frac{E_1}{E_2}\right)^2 \qquad \ldots\ldots(3).$$

And again, with rods of the same metal and similar coating film, but of different diameters, it becomes possible to find the effect of curvature on emissivity, for in this case

$$\frac{\epsilon_2}{\epsilon_1} = \frac{d_2}{d_1}\left(\frac{E_1}{E_2}\right)^2 \qquad \ldots\ldots(4).$$

Experiment. It might be of interest to describe briefly an apparatus which was designed to test the validity of equation (2). The two metal rods r, r (see Fig. 1), rather less than a metre long, and coated with a thin film of heat resisting black paint, were screwed into the thick wall of a copper boiler H, the same thick wall being firmly fixed to a substantial wooden upright which also served to shield the rods from the radiation of the burner beneath the boiler. Every care was taken to ensure rigidity at the fixed ends of the rods.

At some distance from their free ends the rods rested in V's cut in a fixed wooden support (to prevent bending more than one support is necessary for thin rods) and at points close

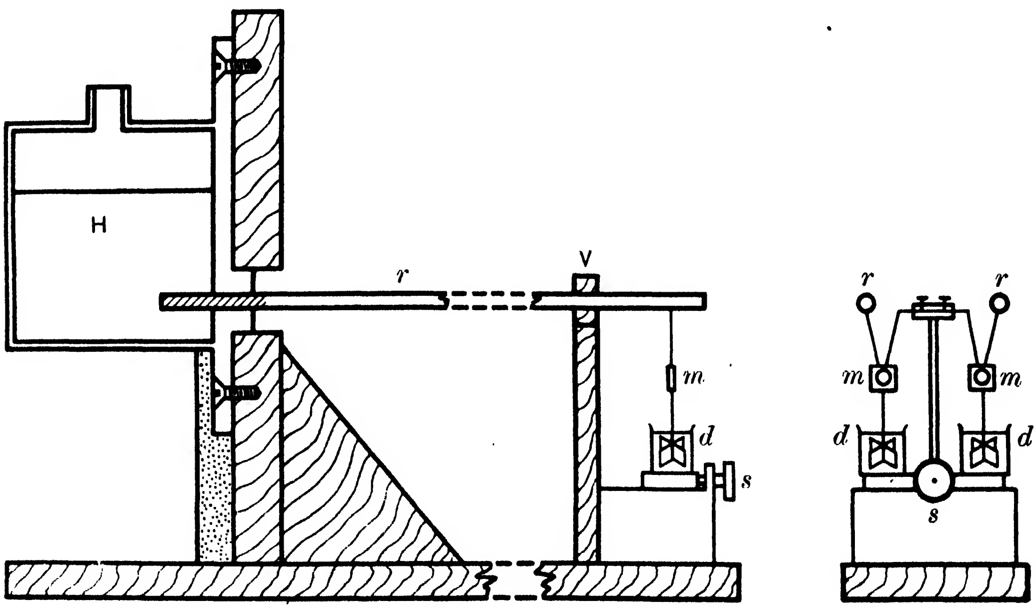


Fig. 1

to the free ends threads were fixed to two doubly suspended concave mirrors *m*, *m*, throwing two images of the same lamp on to one galvanometer screen. The two inner threads from the mirrors were attached to the ends of a horizontal wire fixed to an upright which could be moved parallel to the rods through small distances by means of the screw *s*. Thus the relation between the scale readings could be readily obtained. It was necessary to damp out mirror oscillations by vanes moving in the dashpots *d*, *d*.

The magnification possible with this arrangement allows the use of a comparatively small temperature excess at the heated ends of the rods. The experimental results given later were obtained using boiling water to heat the rod ends and the horizontal distance between the points of suspension of each mirror was some seven or eight millimetres. Large deflections could certainly be obtained for a temperature excess of from 10 to 20° C. by reducing the distances between the points of suspension.

It should be remembered, however, that when the temperature excess is reduced, it becomes increasingly important to make a correction for any change in air temperature during an experiment.

The following readings of an actual experiment give some idea of the magnitude of the measurements involved:

Copper rod ...	Diam. 7·90 mm.	Surfaces similar.
Aluminium rod ...	Diam. 7·94 mm.	

Mirror deflections produced by turning the screw *s* (see Fig. 1). Zero in middle of galvanometer scale; readings in cm.

Cu mirror readings	5·5	0·7	1·7	9·5	17·8	22·5
Corresponding *Al* mirror readings	5·1	0·6	1·5	8·7	16·4	20·8
Differences. *Cu*	9·5–5·5 = 4·0		17·8–0·7 = 17·1		22·5–1·7 = 20·8	
Differences. *Al*	8·7–5·1 = 3·6		16·4–0·6 = 15·8		20·8–1·5 = 19·3	
Ratio: $\frac{Cu \text{ deflection}}{Al \text{ deflection}}$	1·11		1·08		1·08	

Ratio adopted 1·08

Boiler heated. Steady conditions reached 30 min. after water began to boil.

$$Cu \text{ deflection} = 22{\cdot}5 - 3{\cdot}5 = 19{\cdot}0.$$
$$Al \text{ deflection} = 20{\cdot}8 - 0{\cdot}9 = 19{\cdot}9.$$

Whence
$$\frac{E_{Al}}{E_{Cu}} = \frac{19{\cdot}9}{19{\cdot}0} \times 1{\cdot}08 = 1{\cdot}13.$$

Substituting in equation (2)
$$K_{Al} = K_{Cu} \cdot \frac{7{\cdot}90}{7{\cdot}94}\left(1{\cdot}13 \times \frac{\alpha_{Cu}}{\alpha_{Al}}\right)^2.$$

Taking $K_{Cu} = {\cdot}918$, $\alpha_{Cu} = 167 \times 10^{-7}$, $\alpha_{Al} = 255 \times 10^{-7}$,
we find $K_{Al} = {\cdot}501$.

A few other results for metal rods compared with the copper rod are given below:

Metal	Diam. (mm.)	Coefficient of exp. × 10^7	Total exp. (Cu = 1)	Conductivity (observed)	Conductivity (Kaye & Laby)
Copper	7·90	167	1·00	—	·918
Zinc	8·34	260	·89	·287	·265
Aluminium	7·94	255	1·13	·501	·504
Iron	7·96	110	·31	·198	·161
Brass	8·10	189	·60	·251	·260

Considering the fact that thermal conductivities obtained by different observers vary very considerably, and that the metals used were commercial samples with no guarantee of purity, the results are satisfactory.

A METHOD OF ADJUSTING SPECTROMETERS WITHOUT THE USE OF A PLANE-PARALLEL PLATE. By A. A. LEBEDEFF. Optical Institute, Leningrad, Russia.

[*MS. received, 25th October, 1926.*]

THE method which is usually employed to adjust the optic axis of the collimator and telescope of a spectrometer perpendicular to the axis of rotation of the telescope, consists in using a plane-parallel plate which is placed on the table of the spectrometer and adjusted with the aid of a Gauss eye-piece perpendicular to the optic axis of the telescope; after this the telescope is rotated through an angle of 180°, and if the optic axis of the telescope is now not perpendicular to the plane of the plate, the perpendicularity is to be restored, half by varying the inclination of the plate and half by inclination of the telescope. This operation must be repeated several times because usually there are no marks in the field of the telescope which would render the performance of this bisecting adjustment sufficiently accurate at once, and this makes this operation rather tedious. Moreover, a plane-parallel plate of good quality is not always at hand, and with a plate having the faces not quite parallel this operation becomes still more tedious.

Very simple reasoning will show that we can easily dispense with the plane-parallel plate and that the only thing which is necessary for the adjustment is a good reflecting plane, for which we may conveniently use one of the faces of the prism under test. In fact, suppose OA (Fig. 1) represents the direction of the axis of rotation of the telescope and OC is some arbitrary position of the optic axis of the collimator. First we place the telescope opposite to the collimator and adjust their optic axis parallel to each other, i.e. we direct the optic axis of the telescope parallel to OJ, where OJ is the prolongation of the line CO. Now we rotate the telescope through an angle BOD (for instance about 90°) so that its axis is now parallel to OJ' and adjust the reflecting plane upon the table in such a manner that the line OC after reflection will coincide with OJ' or, in other words, that the middle point of the slit would again coincide with the cross-lines of the telescope, for which the normal to the reflecting plane ON must bisect the angle COJ'. It may be easily seen from the equality of the spherical triangles $J'DN$ and CFN (because $J'D = JB = CF$, $J'DN = CFN = 90°$ and $J'ND = CNF$) that in this case the normal ON must necessarily lie in the equatorial plane BDF, and therefore ON is perpendicular to OA, the axis of rotation of the telescope. There remains now only to adjust the optic axis of the telescope perpendicular to the reflecting plane, and then to place the telescope in line with the collimator and adjust the axis of the collimator parallel to that of the telescope.

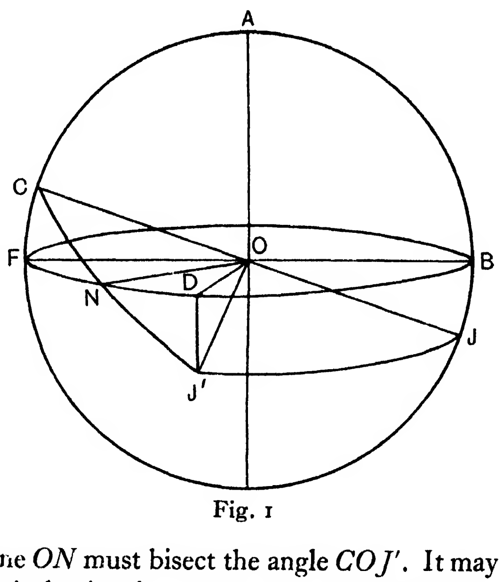


Fig. 1

Thus, the entire adjustment consists of the following four operations.

(1) Place the telescope in line with the collimator and make their optic axes parallel.

(2) Rotate the telescope through an angle of about 90° and adjust the reflecting plane so as to make the axis of the telescope coincide again with the axis of the collimator after reflection.

(3) Adjust the axis of the telescope perpendicular to the reflecting plane.

(4) Adjust the axis of the collimator parallel to the axis of the telescope.

If the prism under test is not too large and does not fully screen the beam of light emerging from the collimator, then it is possible to perform the whole adjustment without even dismounting the prism, and thus one may check the adjustment at any desired moment in the course of the measurements without touching the prism under test.

The above method of adjusting the spectrometer is very simple and convenient, and as I have never met any indication about it in literature I thought it not superfluous to give a description of it.

A NEW ACOUSTIC GENERATOR. THE AIR-JET-GENERATOR. By J. HARTMANN and BIRGIT TROLLE.

The Pitot-Curve and the Intervals of Instability

The new acoustic generator described in the following comprises as a fundamental member an air-jet with a velocity higher than that of sound. A jet of this kind is produced when air is emitted into the free atmosphere from a container in which the absolute pressure exceeds 1·9 atm., the excess pressure thus being 0·9 atm. The jet shows a peculiar structure

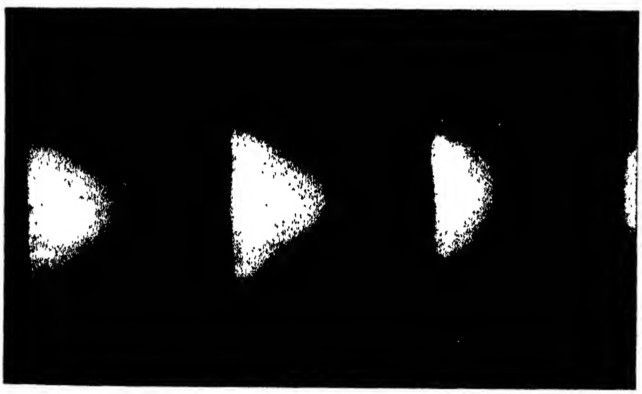


Fig. 1. The air-jet

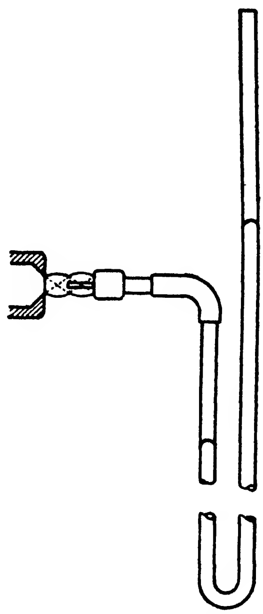


Fig. 2. The Pitot-apparatus

of which a picture may be obtained by means of the method of striae. Fig. 1 shows a photograph produced in this way. As will be seen, the jet is divided into sections of nearly equal length. Corresponding to this division the static pressure varies, as shown for instance by Stodola, in a regular periodic way along the axis of the jet; exhibiting minima in the middle points of the sections and maxima in the planes separating the sections. It was

Mach who first disclosed the structure of the jet by means of photographs, and it was Prandtl who gave the explanation of it. The division of the jet into sections originates from waves emitted from the edge of the jet-orifice. These waves are of much the same kind as those which are produced by a projectile flying through air with a velocity greater than the velocity of sound. The waves cross and recross the jet, being reflected from the surface of the jet, and so produce the picture shown in Fig. 1. Prandtl has derived the formula

$$\Delta = 1{\cdot}2 . d\sqrt{p - 0{\cdot}9} \qquad \ldots\ldots(1)$$

for the length Δ of the section of a cylindrical jet emitted into the free atmosphere. In the formula d denotes the diameter of the jet-hole and p the excess pressure in the container measured in atmospheres. The formula agrees fairly well with observations, the constant 1·2 being perhaps rather too high. Moreover the first section is found to be of somewhat greater length than the following sections, namely about $\frac{8}{7}$ of these.

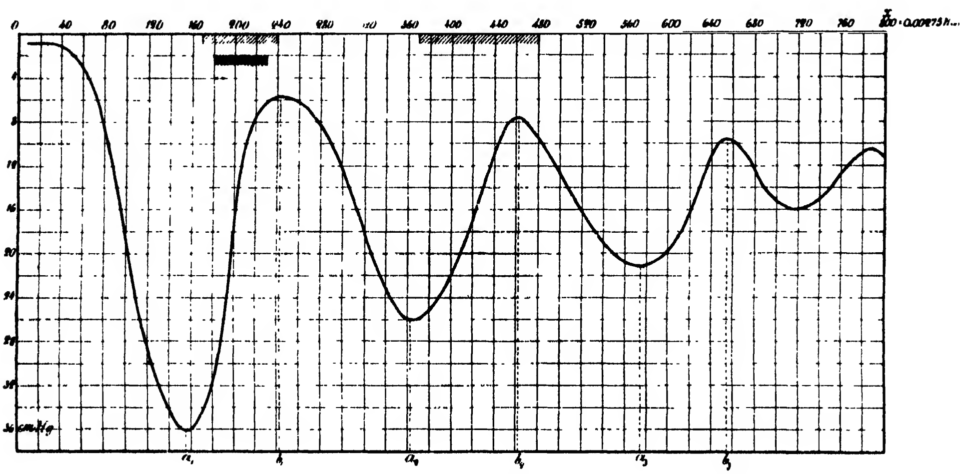


Fig. 3. Pitot-curve

On a certain occasion one of the authors introduced the sound of a Pitot-apparatus, Fig. 2, into the axis of the jet and moved it along the axis, observing the variations in the reading of the Pitot-manometer*. It proved that the pressure indicated varied in a very regular manner as shown in Fig. 3. Close to the nozzle the manometer shows the same pressure which is present in the container. But when the sound is moved outwards the pressure falls and rises periodically. It was later on found that the minima of the Pitot-curve were very nearly over the middle points of the sections in the picture Fig. 1, the maxima over the border-lines between the consecutive sections. The periodical variation of the Pitot-pressure is a remarkable feature. For if the general laws of motion of a gas hold good—and especially the adiabatic law—one should expect a nearly constant reading of the manometer coinciding with the pressure in the container. An explanation of the deviation is indicated at the end of the paper. Here it suffices to point out that the periodic variations in the Pitot-curve account for the acoustic generator, which was invented in the following way. It was found that when a Pitot-sound with a fairly wide aperture was used, it was practically impossible to read the manometer when the mouth of the sound was within those parts of the jet where the Pitot-pressure rises, i.e. the parts

* Jul. Hartmann, *Det kgl. danske Vidensk. Selsk. math.-fys. Medd.* **1** (1919) 13, and *Phys. Rev.* **20** (1922) 719.

a_1b_1, a_2b_2, a_3b_3 of Fig. 3. In these intervals, the intervals of instability, the Pitot-apparatus behaved in a peculiar way. It first took in air to a certain pressure, then discharged the air, then again took in air to the same pressure as before, discharged, etc.

THE PULSATOR

The sound of the Pitot-apparatus was replaced by the mouth of a container, Fig. 4. When the mouth was adjusted in one of the intervals of instability a_1b_1, a_2b_2, Fig. 3, the container behaved naturally in quite the same way as the manometer, periodically taking in and discharging air. The period of the pulsations depends on the diameter of the aperture, the size of the container, and the position of the mouth in the interval. It is the greater the greater the volume and the less the aperture. It may easily be varied from say 1 per min. to many hundreds per sec. With higher frequencies, the pulsations are of course heard as a note, not a very pure note but rather of the same character as that of a siren. The sound source may be termed a pulsator.

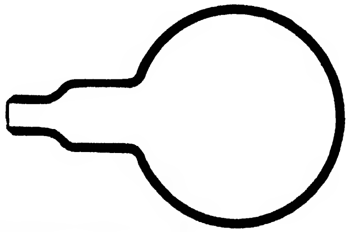


Fig. 4. Pulsator

The operation of the pulsator has recently been elucidated by means of the same optical method which has often been used for the photographing of air-jets*. In Fig. 5 a number of photographs have been reproduced, representing the process of the pulsation. Fig. 5 *h* shows the jet during the phase of filling, the pulsator being to the left in the picture. During this phase no change in the aspect of the jet is seen, while a manometer connected to the pulsator indicates a rise in the pressure. Suddenly the discharge sets in with a characteristic click, and the picture changes. What happens is that an air-jet of nearly the same kind as that emitted from the nozzle of the air-container bursts forth from the mouth of the pulsator. This jet is clearly seen in Fig. 5 *a–f* coming from the left. Where the main jet and the pulsator jet meet a layer of some width is formed. Through this layer the air from the two jets escapes sideways. On both sides of the layer a sharp line is seen. This is nothing but the wave which is always seen in front of an object moving relatively to air with a velocity higher than that of sound. The wave is especially known from projectiles and is often termed the Mach-wave. During the process of discharge the layer of collision is gradually pressed back against the pulsator, at first slowly, later on at a greater rate. At last the resistance against the main jet suddenly gives way and the process of filling again sets in.

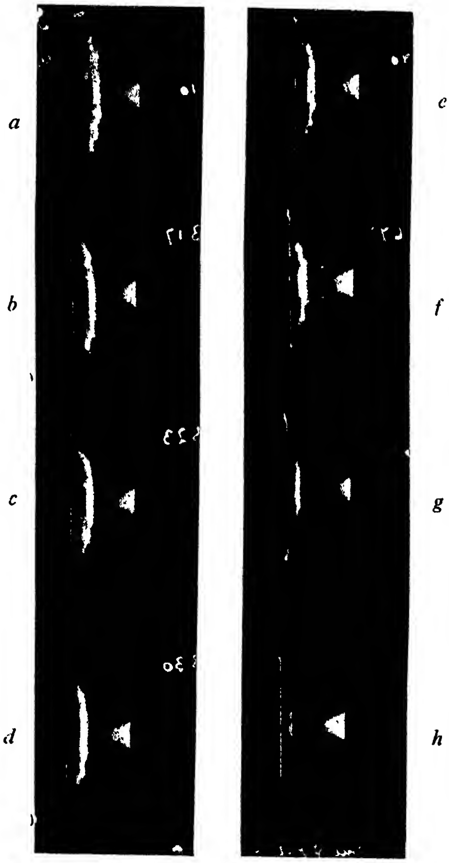


Fig. 5. Instantaneous photographs of pulsations

* Jul. Hartmann and Birgit Trolle, "New Investigation on the Air-Jet Generator," *Det kgl. danske Vidensk. Selsk. math.-fys. Medd.* 7 (1926) 6.

THE OSCILLATOR

Again the pulsator may be replaced by a simple cylindrical oscillator, Fig. 6. Then one gets more harmonic vibrations of the air with a frequency coinciding roughly with the natural vibrations of the oscillator. By reducing the dimensions of the oscillator to a very small size (for instance d and l Fig. 6 equal to about $\frac{1}{2}$ mm.) oscillations and sound waves of frequencies of 100,000 or more may be produced. The intensity of the waves is relatively very high, due to the density of energy in the jet.

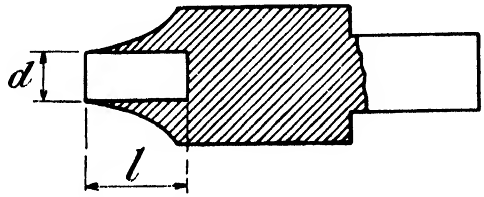


Fig. 6. Cylindrical oscillator

The vibrations of the air in or rather in front of the oscillator have been made visible in much the same way as was used in the case of the pulsator. In the first column of Fig. 7 the mouth of the oscillator is outside the interval of instability and consequently no vibrations take place and no waves are emitted. In front of the oscillator is seen a sharp line, the wave-front mentioned above. In the following column and in the first two pictures of the third column the oscillator is inside the first interval of instability. In front of the oscillator a rather wide band is now seen. It indicates a number of positions of the front wave during the vibration of the air in the oscillator, each photograph being taken with the jet illuminated by a great number, say 50, of electric sparks. In the following pictures the vibrations first disappear then reappear. Whenever waves were emitted, which could be shown by means of a Kundt-tube, the front wave described a band.

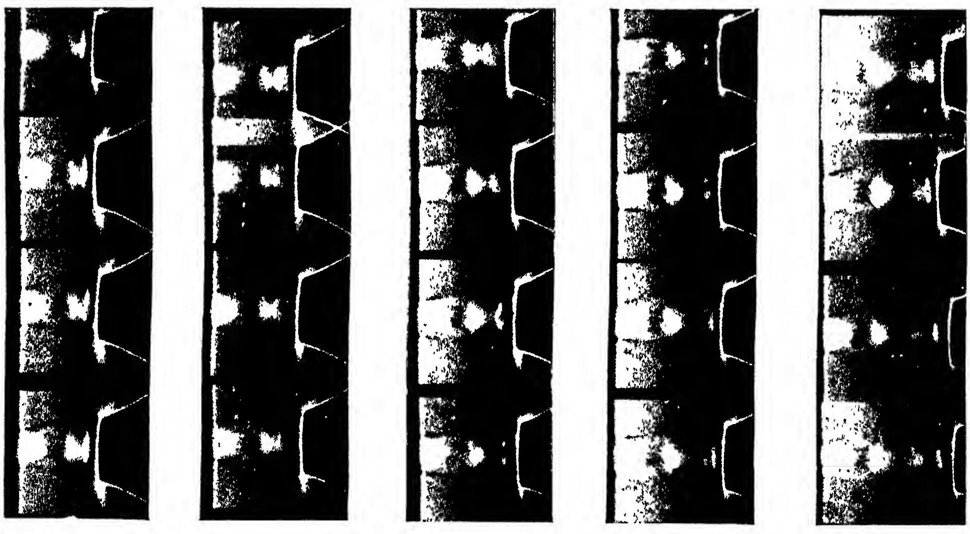
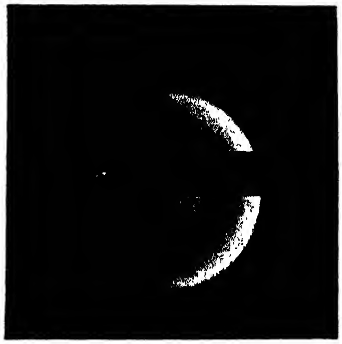


Fig. 7. Photographs of oscillations

A proof of the high intensity of the vibrations may be found in the fact that it has proved possible to photograph the continuous train of waves emitted from the oscillator, in Figs. 8–9 two photographs have been reproduced. Fig. 8 corresponds to a frequency 86,700 and was

obtained with a hydrogen-jet. Fig. 9 represents vibrations with a frequency of 52,000 and was obtained with a jet of atmospheric air. The distance between two circles in all pictures taken is equal to a whole wave-length. This fact indicates that the profile of the wave differs very markedly from the harmonic. In all probability the waves proceed with a very steep front, it being this front which is seen in the pictures as a line of more or less sharpness. Fig. 10 and Fig. 11 finally show waves reflected from the plane surface of the nozzle and interfering with the wave-system proceeding directly from the oscillator.



Figs. 8, 9. Wave photographs

Figs. 10, 11. Wave photographs

The Wave-length

In the following we shall only consider the generator furnished with a cylindrical oscillator. The length of the waves emitted from the oscillator may be measured by means of a Kundt-tube. Fig. 12 represents samples of the dust-figures, the smallest corresponding to about 120,000 periods per sec. The Kundt-tube method was used for the study of the variation of the wave-length with the position of the mouth of the oscillator in the jet, i.e. its distance x from the nozzle. In Fig. 13 a typical result is reproduced. The abscissa is x, the ordinate quarter of the length of the produced waves. S_2, S_3, S_4 denote the positions of the borders of the consecutive jet-sections, S_1 the place of the nozzle. The vibrations of the oscillator set in when the mouth of the oscillator is very nearly at that point x_0 of the jet where the Pitot-curve has its minimum. As will be seen in Table I below, the wave-length in this position coincides rather closely with the natural wave-length of the oscillator, i.e. with the wave-length, which may be calculated from

$$\lambda/4 = l + 0{\cdot}3d, \quad \text{for } x = x_0 \qquad \text{......(2)},$$

where l is the depth of the oscillator and d its diameter. When now the mouth of the oscillator is carried farther away from the nozzle, the quarter-wave-length increases approximately with the amount of the displacement Δx, thus

$$\lambda/4 = l + 0{\cdot}3d + \Delta x, \quad \text{for } x = x_0 + \Delta x \qquad \text{......(3)}.$$

This simple law indicates that the front of the vibrating mass of air proceeds to a fixed point or rather plane in the jet, independent of the position of the oscillator in the interval of

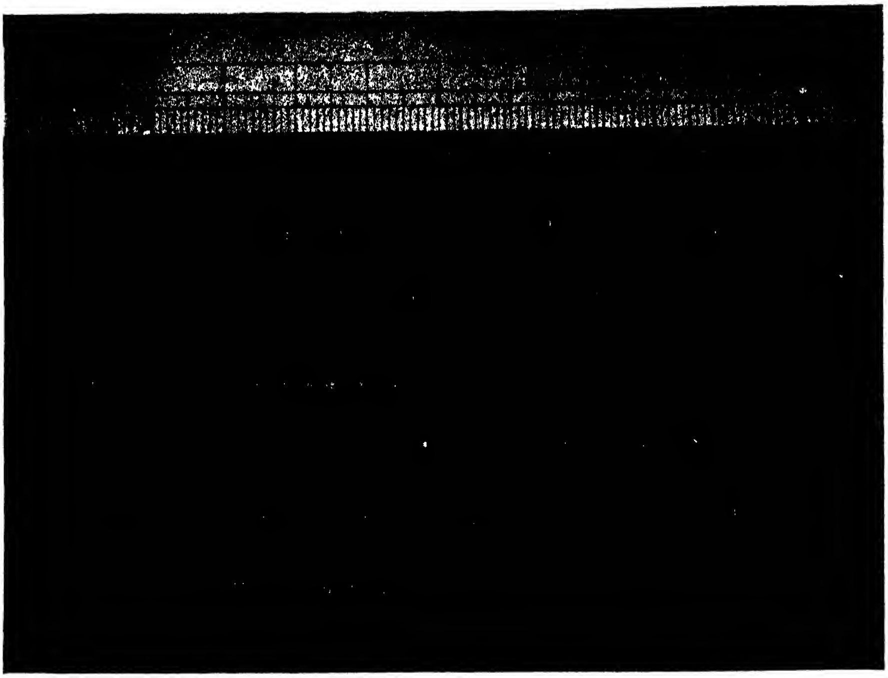


Fig. 12. Dust-figures in Kundt-tubes

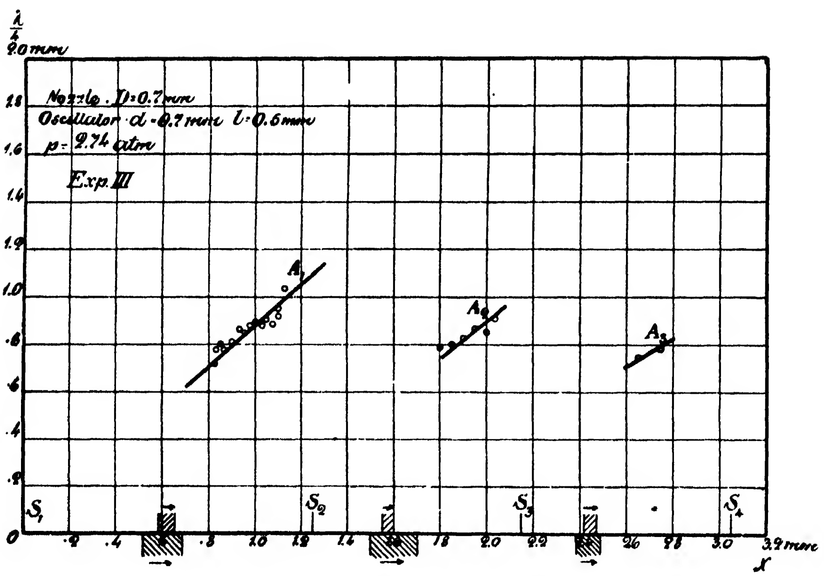


Fig. 13. Variation of λ/4 with x

instability. The law (3) holds good with an exactness which is the better the lower the excess pressure in the container from which the jet is emitted. With higher pressures the increase in λ/4 is not quite as large as the displacement. It thus seems that the plane referred to moves a little in the same direction as the oscillator.

In Table I the results of investigations on a number of jets and oscillators with varied excess pressure p have been represented.

Table I. *Wave-length, dimensions and position of oscillator*

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
d_0	d	l	p	x_0'	$(\lambda/4)_0$	$(\lambda/4)_m$	x_0	x_m	$(\lambda/4)_0 + x_m - x_0$	$l + 0{\cdot}3d$
mm.	mm.	mm.	atm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.
0·7	0·7	0·5	2·74	0·8	0·7	1·0	0·80	1·1	1·00	0·7
0·7	0·7	0·5	3·79	0·8	0·7	1·1	0·95	1·6	1·35	0·7
0·7	1·0	0·5	3·80	0·8	0·6	1·2	0·85	1·6	1·35	0·8
0·7	1·0	0·5	5·65	1·1	0·6	1·3	0·85	2·0	1·75	0·8
4·6	5·0	5·0	6·00	7·3	6·5	11·0	7·00	15·0	14·50	6·5
4·6	5·0	10·0	6·00	7·3	11·5	18·0	7·00	17·0	22·50	11·5
4·6	5·0	25·0	6·00	7·3	30·0	39·0	8·00	20·0	42·00	26·5

d_0 diameter of nozzle.
d diameter of oscillator.
l depth of oscillator.
p excess pressure in container.
x_0' first minimum in Pitot-curve.
$(\lambda/4)_0$ lowest value of quarter-wave-length.
$(\lambda/4)_m$ highest value of quarter-wave-length.
x_0 distance at which vibrations set in.
x_m distance at which vibrations stop.

It is seen that x_0, as stated, very nearly coincides with x_0', and that $(\lambda/4)_0$ is equal to $l + 0{\cdot}3d$. Not quite so perfect is the agreement between $(\lambda/4)_m$ and $(\lambda/4)_0 + x_m - x_0$.

Design and Application of the Generator

From the foregoing a good deal of information necessary for the design of the generator may be derived. Systematic investigations with regard to the connexion between the efficiency and the various parameters, viz. pressure, depth of oscillator, etc., would be very desirable, but have not yet been carried out. Some knowledge has, however, been gathered from the experiments already made, and a brief account of these experiences is here given as follows.

The diameter of the oscillator should be about the same size as that of the nozzle. Perhaps it may advantageously be made some few per cent. larger. The highest efficiency is undoubtedly obtained when the depth of the oscillator is 1–2 times the diameter. The intensity of the vibrations and thus the efficiency has as a rule a maximum near that end of the interval of instability which is farthest from the nozzle. Fig. 14 shows the variation of the amplitude of the vibrations in the oscillator proper within the first and second interval at a certain case. It was stated above that the excess pressure must be at any rate higher than about 0·9 atm. Actually the excess pressure must be essentially higher in order to obtain vibrations of a reasonable intensity. On the other hand the pressure should not be raised above a certain limit, because the efficiency then becomes bad. This is undoubtedly due to the breaking up of the regular structure shown in Fig. 1. The break-down is illustrated in Fig. 15. It takes place at a certain pressure which undoubtedly is the higher the larger the diameter of the jet. Probably one gets in every case the highest efficiency when the excess pressure is somewhat below that at which the structure breaks down. The optimum excess pressure may with a jet-hole of 1 mm. be something like 3 atm., and with a hole of 5 mm. probably about 8 atm. The figures only represent rough estimates derived from various observations.

The circumstance that the depth of the oscillator, with economical generators, cannot be made much larger than the diameter, accounts for the fact that the output of the generator is closely connected with the pitch of its note. A generator for a low note can only be con-

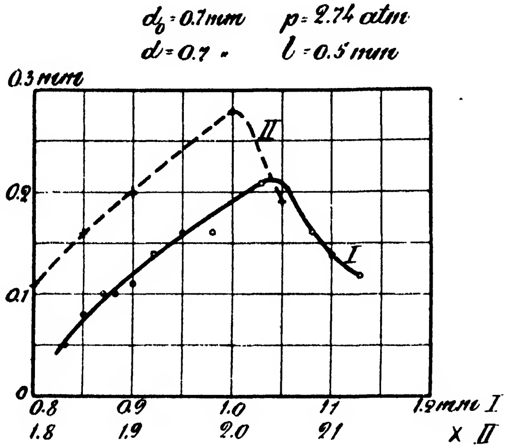


Fig. 14. Amplitude in interval of instability

Fig. 15. Air-jet

structed for a large output. We saw that the minimum wave-length for a generator with a certain oscillator was given by

$$\lambda/4 = l + 0{\cdot}3d \qquad \ldots\ldots(2).$$

Now if l must be made 1–2 times d, and d again very nearly equal to d_0, then

$$\lambda/4 \sim 1{\cdot}3d_0 - 2{\cdot}3d_0.$$

In Table II there is given a series of numbers for the frequencies N which may be produced by means of the jets, the diameters of which are stated in the first column. The velocity of sound is assumed to be 340 m./sec.

It should be remembered that with jets of hydrogen the frequencies will be about 3·5 times as high. It follows that the generator is especially suited for the production of very high frequencies. But on the other hand it is seen that the construction of generators for signalling purposes is not out of the question, provided a comparatively high intensity is demanded.

Table II. *Frequency and thickness of the jet*

	$l=d$		$l=2d$	
d_0 mm.	$(\lambda/4)_0$ mm.	N_0 ∾ per sec.	$(\lambda/4)_0$	N_0 ∾ per sec.
1	1·30	65,400	2·30	37,000
2·5	3·25	26,200	5·75	14,800
5·0	6·50	13,100	11·5	7,400
10·0	13·0	6,540	23·0	3,700
15·0	19·5	4,360	34·5	2,460
20·0	26·0	3,270	46·0	1,850
25·0	32·5	2,620	57·5	1,480
30·0	39·0	2,180	69·0	1,230

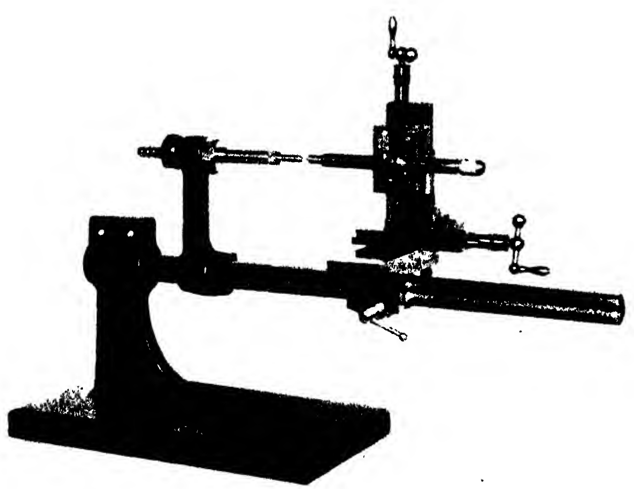


Fig. 16. Generator for demonstration purpose

Fig. 17. Generator of simple device

Some few forms of the generator are shown in Fig. 16–18. The generator Fig. 16 is destined for general use in the laboratory and for demonstration. The nozzle and oscillator are interchangeable and the position of the latter may easily be adjusted by a triple slide arrangement. A simpler form is shown in Fig. 17. It has been constructed for special experiments in which all larger reflecting surfaces should be avoided. Finally Fig. 18 shows in drawing a generator under construction for signalling purposes and designed according to the views set forth above.

The Theory of the Generator

The conception to which we have been led with regard to the working manner of the new generator may be elucidated by means of Fig. 19. In this figure *a*, *b*, *c*, *d*, *e* indicate part of the Pitot-curve of the air-jet, the nozzle being at *o*. *O* is the aperture of the pulsator. At a certain moment the latter may be filled up to the pressure *Oc* corresponding to the

position of *O*. There might now be a kind of equilibrium, but the balance cannot be stable. Any small disturbance which causes air to penetrate from the pulsator will set up a jet with a Pitot-curve *ca* in which the pressure exceeds the pressure in *abcd* to the distance *a*. Therefore it may safely be predicted that a jet will actually penetrate from the pulsator to the said distance and thus discharge the pulsator. During this process the Pitot-curve of the pulsator jet falls gradually as indicated in the figure. Presumably it continues to fall until

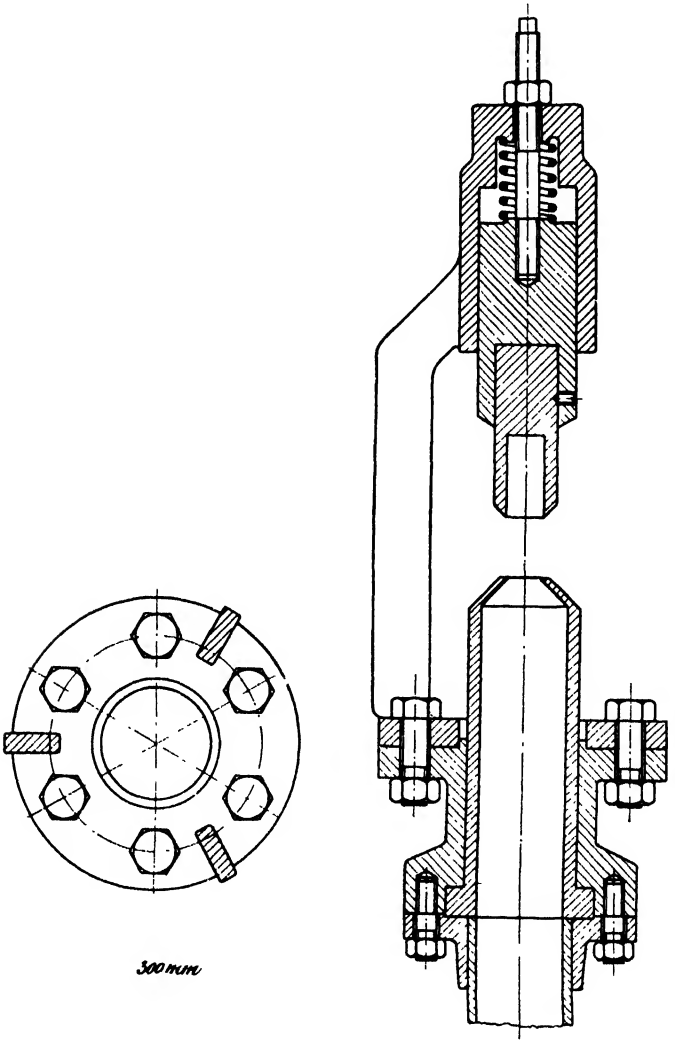


Fig. 18. Generator for signalling purpose

the position $c''b$, when it just touches *abcd*. The conditions are now again instable which means that the main jet again bursts forth and fills the pulsator up to the pressure *Oc* or nearly to that pressure. The explanation is, as will be seen, in qualitative agreement with the pictures in Fig. 5. Throughout the explanation the word pulsator has been used for the purpose of fixing the ideas. We might as well have spoken about an oscillator, the only difference, presumably, being that the natural frequency of the oscillator will force itself on the process of filling and discharging probably through waves running down the oscillator and being reflected alternately from the bottom and the mouth of the oscillator.

The explanation given above has been put to test in a new series of investigations and found correct in its main features. We thus fairly well understand the working manner of the new generator. Obviously the generator depends on the particular shape of the Pitot-curve. So in order to clearly see the nature of the generator, we still have to explain how it comes, that the Pitot-pressure varies periodically and is not, as might be expected, simply constant and equal to the pressure in the container from which the jet is emitted.

To understand this, a phenomenon must be recalled, to which the attention was probably first drawn by Riemann. In a stream of air with a velocity higher than that of sound there may arise a layer of extremely small width inside which irreversible processes take place.

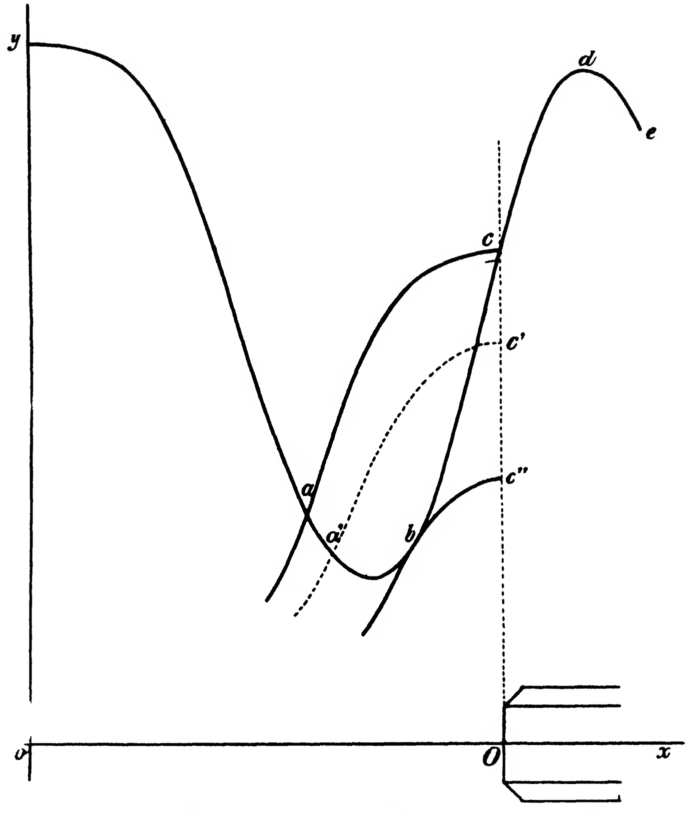


Fig. 19. Theory of generator

Due to these processes the layer will act much as a screen, diminishing the pressure of the stream of air on an obstacle placed down-stream with regard to the said layer. The decrease is the higher the higher the velocity in front of the layer. In our experiments with the Pitot-apparatus and with pulsators and oscillators a layer of the kind referred to is formed in front of the Pitot-sound or the mouth of the pulsator and oscillator. It is identical with the sharp lines in front of the oscillator in the first pictures of Fig. 7, and with the lines on both sides of the collision layer in Fig. 5. The velocity now varying periodically along the axis of the jet, the indication of the Pitot-manometer must, according to the way in which the "screen-effect" depends on the velocity, vary, in much the same manner, i.e. periodically. Thus, ultimately the new acoustic generator is a consequence of the Riemann phenomenon.

A NEW FORM OF "SMOKE-BOX" FOR DEMONSTRATING THE LAWS OF OPTICS. By W. O. CLARKE, B.Sc., of St John's School, Leatherhead, Surrey.

For many years past, teachers of science have tried spasmodically to render optical experiments more interesting and instructive by using smoke or dust to make visible the path of beams of light.

In some cases a puff of cigarette smoke in front of a projecting lantern gave a momentary visibility to the beams; or advantage could be taken of suspended dust particles, stirred up by the feet of students, to demonstrate effects such as the convergence produced by a convex lens.

More ambitious attempts usually involved the use of a chemically prepared smoke and somewhat cumbersome apparatus, with consequent lack of mobility and difficulty in setting up the experiments.

A successful attempt has recently been made to produce a compact apparatus capable of demonstrating, by means of visible beams, a large number of optical experiments, and this is now being put on the market under the name of "CLARKE'S OPTICAL SMOKE-BOX" (Patent No. 229445). It was first shown in 1924, at a meeting of the Science Masters' Association, and more recently was exhibited at the Optical Convention (1926), and at the Royal Institution (April 23rd, 1926).

The chief points that have been borne in mind in designing the "Smoke-Box" are:

1. The necessity for an easily obtained and permanent smoke-cloud.

2. The performance of as large a number as possible of different experiments by means of one set of apparatus.

3. The provision of facilities for making a rapid change from one experiment to another.

The construction and use of the apparatus will be made clear by the following description and accompanying photographs:

The apparatus consists of a glass-fronted box or container (size about 2 ft. 6 in. × 1 ft. × 1 ft.) which can be filled with smoke generated by means of a small piece of smouldering material inserted in the box through a tube. More conveniently, tobacco smoke may be blown into the box. The cloud is rendered stable and uniform by agitation with an air-blast produced by a bulb attached to the box, and will remain for from one to two hours. The continuous and uniform cloud so produced is invisible except when illuminated by a beam of light, thus the paths of beams are indicated very clearly.

Light from an arc (shown in Fig. 1 on left of box) enters the box through a system of lenses and shutters so arranged that converging, diverging or parallel beams may be produced at will, the shutters being slotted and pierced in such a manner that broad or flat, and single or multiple, beams may be utilized.

The optical apparatus with which the demonstrations are performed is arranged at the back of the box, out of the path of the beams. Each piece of apparatus, however, is mounted in such a way that it can be pushed forward, when required, into the path of the beams, by means of rods passing through the back of the box. Thus in Fig. 11, a convex lens and a concave mirror have been so pushed forward into the path of a multiple beam, the mirror being tilted in order to show up the reflected rays.

The equipment of the box preferably consists of: 1 Convex Lens, 1 Concave Lens, 1 Half-Cylinder, 1 Prism, 1 Convex Mirror, 1 Concave Mirror, and 1 Plane Mirror. Each

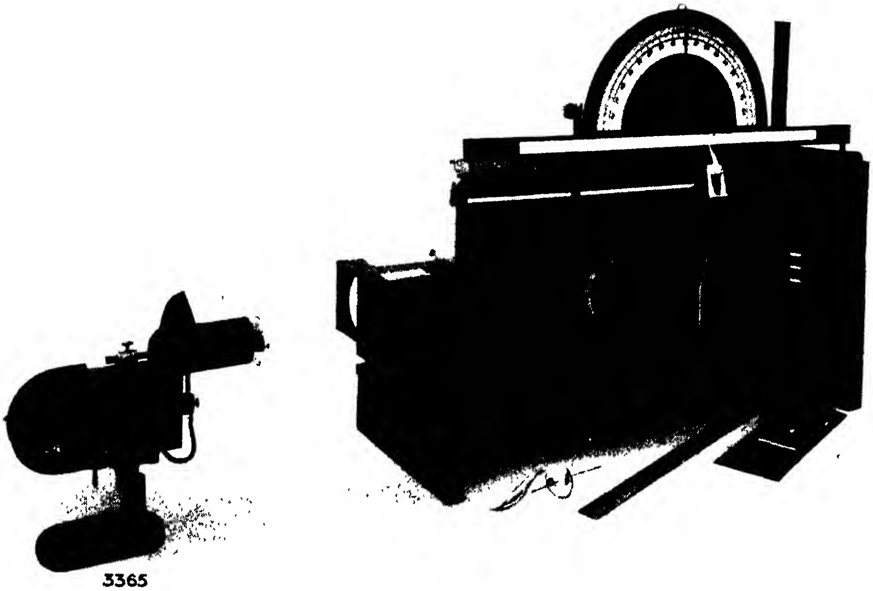


Fig. 1

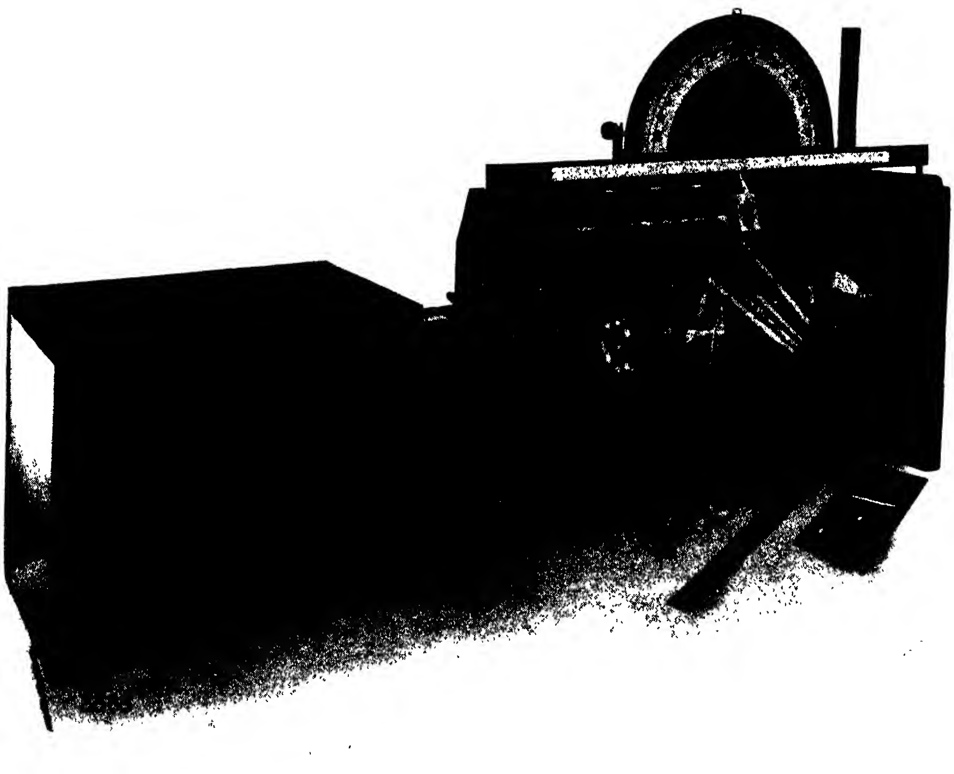


Fig. 2

of these is capable of rotation about a horizontal axis. By lifting the glass front of the box, any piece of apparatus can be removed, and additional apparatus (e.g. a diffraction grating) may be inserted.

For the purpose of making measurements, scales are provided, viz. Circular Scale (seen on top of box) for measuring amount of rotation of mirror, half-cylinder, etc.; Horizontal Scale (used in conjunction with an indicating rod) for measuring focal lengths, etc.; and two Vertical Scales which can be inserted in a slot on right of box for measuring deviation, etc. in refraction experiments.

In order that the demonstrations may be performed from behind, windows are arranged in the top of the box to allow the operator to view the beams, and to check the adjustment of the various pieces of apparatus; and for the purpose of giving lateral motion to special pieces of apparatus, a longitudinal slot is formed in the floor of the box.

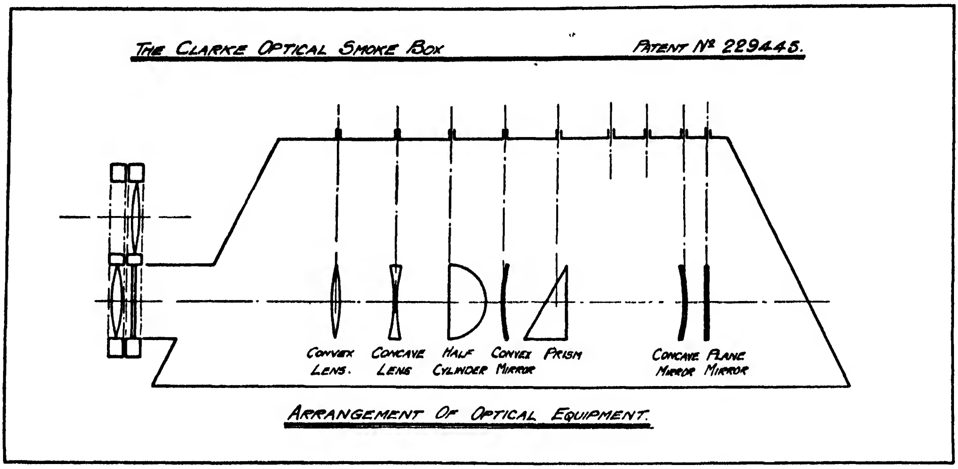


Fig. 3

The following characteristic features are associated with the demonstrations:

(1) The extremely sharp and well-defined beams.

(2) The ease with which the number and nature of the beams can be varied.

(3) Beams are produced "in the solid," not in one plane only.

(4) The rapidity with which the demonstrator can change from one experiment to another, by sliding apparatus in and out of the beams.

(5) The large number of experiments that can be performed with the apparatus.

(6) The optical apparatus used is of the ordinary type (e.g. complete lenses and mirrors are used, not segments).

(7) A completely darkened room is not necessary for the majority of the experiments.

(8) The demonstrations can be arranged to suit either the "wave" or "ray" method of treatment.

It may be remarked that many points of interest, which as a rule pass unnoticed, are strikingly brought out by use of the Smoke-Box: among these may be mentioned the clear reflections at the front and back surfaces of lenses, showing the loss of light; the appearance of coloured beams in dispersion experiments; and internal and external surface reflections, which are well shown in refraction experiments with the half-cylinder and prism.

The present writer has found that the interest excited by preliminary demonstrations with the Smoke-Box provides the degree of stimulation necessary to enable students to perform the usual "pin" experiments with care and understanding; and when the apparatus is used

in conjunction with the Ripple Tank, a self-contained course (for junior students) on the Wave Theory may be given and strikingly illustrated.

The following is a list of the chief experiments performed with the standard equipment; many others will of course suggest themselves:

Straight line propagation. Shadows. Law of inverse squares. Diffuse reflection; reflection at plane surfaces; angle of incidence = angle of reflection; angle of rotation of beam = twice that of mirror. Concave and convex mirrors, their effect on beams; focal lengths and radii of curvature; $R = 2f$; illustration of relation

$$\frac{1}{v}+\frac{1}{u}=\frac{1}{f}.$$

Refraction at a single plane surface;

$$\frac{\sin i}{\sin r}=\mu.$$

Total reflection at glass-air boundary; critical angle; determination of "μ" from critical angle. Deviation and dispersion produced by a prism; minimum deviation; determination of "μ" from

$$\frac{\sin\frac{D+a}{2}}{\sin\frac{a}{2}}.$$

Total reflection within prism.

Concave and convex lenses, their effect on beams; measurement of focal lengths; illustration of relation

$$\frac{1}{v}-\frac{1}{u}=\frac{1}{f}.$$

By the use of extra apparatus, experiments such as the following may be performed:

Multiple reflection. Double mirror (constant deviation). Total reflection and critical angle for a liquid-air boundary. Diffraction grating (transmitted and reflected spectra shown by visible beams). Polarization (disappearance of complete beam when Nicols crossed). Path of rays through optical systems; and others.

It will be seen that the majority of the experiments usually necessary for an elementary course in Light can be demonstrated with the aid of the Smoke-Box.

As regards the size of classes, the apparatus is at present proportioned to suit the needs of a class of from 20–40 students: a greater number would require more generous dimensions for the apparatus.

The Optical Smoke-Box is manufactured by Messrs G. Cussons, Ltd., of Manchester.

THE FORMATION OF FILMS OF LEAD SULPHIDE ON GLASS SURFACES.

This Investigation was carried out by H. L. SMITH, B.Sc., F.I.C. British Scientific Instrument Research Association.

This investigation was undertaken at the request of a member of the Association who wished to use the process to obtain an even film on a glass surface which would reduce considerably the intensity of transmitted light while giving only feeble reflection.

The process is one developed by the late Professor Emerson Reynolds. Some difficulty has been experienced in obtaining good films of even character.

During the investigation a number of different glasses were used and some interesting results were obtained. It was found that not only the initial treatment of the surface of the glass influenced the result but that the composition of the glass had a pronounced effect on the character of the film.

The process briefly described is as follows: Two solutions are required.

Solution 1. Lead acetate, 69 grm., and sodium potassium tartrate, 52 grm., are separately dissolved in water and the solutions, filtered if necessary, are mixed together. The precipitated lead tartrate is washed free from acetates by adding several (e.g. 4 or 5) litres of water, allowing the precipitate to settle and decanting the clear liquid. This is repeated and finally the supernatant water is syphoned off as completely as possible. The moist lead tartrate is dissolved in a solution of 25 grm. of sodium hydroxide of such strength that the whole resulting liquid can be made up to 1000 c.c.

Solution 2. This is made by dissolving 20 grm. of thiocarbamide in water so as to make 1000 c.c. of solution.

The process of depositing the film as prescribed by Professor Emerson Reynolds. The glass to be covered is directed to be cleaned in nitric acid followed by washing in distilled water. Having determined the volume of liquid required to cover the glass contained in a suitable vessel, the following quantities of the solutions and water are used. If the volume of liquid be x, take water $x/2$, thiocarbamide solution $x/3$ and lead tartrate solution $x/6$. First mix the water and thiocarbamide solution and $\frac{1}{6}$th of the prescribed volume of the lead tartrate solution. In this mixture the glass, held in a brass holder, is immersed and the vessel is heated in a water bath until the liquid reaches a temperature of 60° C. It is then allowed to cool to 50° C. when the liquid should be of a dark sherry colour. At this stage the remaining $\frac{5}{6}$ths of the lead tartrate solution are added. The liquid is kept at 50° C. while the glass is moved about in it until a film of the desired character is produced. In practice the time was found to be about 10 min., the film was thin if the time was appreciably less, while no appreciable increase in the depth of the film took place after 10 min.

The glass is next washed under the tap, removing the scum of loose sulphide with the finger. The film on the under side of the glass can be removed by rubbing with a plug of cotton wool or piece of filter paper moistened with dilute hydrochloric acid. Finally the glass and film are directed to be washed with distilled water and dried in a current of air. When dry the film can be polished by rubbing lightly with wash-leather.

The process is based on the formation of lead sulphide from the interaction of alkaline sulphide and an alkaline solution containing lead.

The quantities of lead acetate and sodium potassium tartrate prescribed are nearly equivalent, there being a very slight excess of the tartrate, so that the whole of the lead should be obtained as tartrate. The quantity of sodium hydroxide prescribed is just under the quantity required by theory for the liberation of lead hydroxide from the tartrate and the formation of sodium plumbite $Pb(ONa)_2$. The whole of the lead dissolves, however, forming a clear solution. Thiocarbamide is hydrolysed by aqueous alkaline solutions, alkaline sulphide being formed.

At the temperature to which the mixed solutions are heated the reaction is fairly slow, so there is a gradual formation of lead sulphide due to the reaction of the lead solution with the sulphide.

Notes on carrying out the process. In carrying out the process some difficulty has been found in synchronizing the times at which the liquid has the correct temperature and the correct colour. During the first heating to 60° C. the colour gradually deepens, but there should be no precipitate. The time for adding the remainder of the lead solution is when the colour is correct and there is no precipitate. The best results have been obtained when no precipitate is observed until after several minutes have elapsed after adding the second

quantity of the lead solution. As the precipitate forms in the solution it is important to keep the glass moving in the liquid.

Cleaning of the glass. The method prescribed is to wash with nitric acid and then in distilled water. It was found that more even results were obtained by following the prescribed treatment with a washing in a very dilute solution of sodium hydroxide and again rinsing with distilled water.

For highly polished surfaces, and especially those of some optical glasses, the treatment with nitric acid may appear somewhat drastic and the following method was adopted with success. The glass was first immersed in ether and then alcohol and rubbed gently with a soft linen cloth, rinsed again in alcohol and finally washed in running distilled water. In most cases this method was sufficient, but, in a particular case of one pitch-polished glass, this treatment did not remove all traces of grease or pitch. Washing with benzene before using alcohol was found to clean the glass satisfactorily.

Final treatment of the film. The method prescribed is to wash with distilled water and then to dry in a current of air. It was found very difficult to avoid formation of drops of water which on drying left marks on the film. In parts the film was rubbed off at the edges of the mark and clear glass was left when the film was finally polished with wash-leather.

Experiments showed that the drying was not only accelerated but there was less danger to the film if the glass and film were first immersed in alcohol for a few minutes and then in ether. From the ether, the glass was immediately placed in an oven at 60° C.

Behaviour of various glasses. The glasses first used were: (1) ordinary 3×1 microscopic glass slips of good quality; (2) ordinary plate glass (a soda lime silicate); (3) a soft crown glass of the same kind as was proposed to be used for the finished instrument.

(1) Good even films were not obtained on this glass, they were always patchy.

(2) Some fair films were obtained on this glass, but a good film could not be produced with any certainty. The defects were a bloom which usually extended over the whole film, patches which were of lighter colour compared with the main film and which rubbed off in polishing with wash-leather; also the films were generally uneven in density. The glass was used both as bought and also after being reground and polished; the results on a freshly polished surface were perhaps a little better than the others.

(3) This glass had been ground and polished just before it was received. It behaved much as glass (2), but no film was obtained equal to the best films obtained on glass (2).

Hard crown and medium barium crown glasses. These were optical glasses, optically polished. The films obtained on these glasses were somewhat thin and were mottled.

Lead glasses. A series of lead glasses gave better films than any other glasses. Among them were included an extra light flint, two light flints (*A* and *B*) and a heavy flint.

The glasses were polished and cleaned, at first without wiping the glass. One light flint (*A*) gave a very good film, better than those on the other lead glasses in this series. The films were removed by grinding and the glasses repolished and cleaned. This time they were wiped with a cloth while in the alcohol. With this small difference in procedure quite good films were obtained on the extra light flint and the second light flint (*B*) as well as on (*A*). The light flint glass (*A*) appears to give a surface specially suitable for the deposition of lead sulphide films by this process and to be somewhat better in this respect than the other glasses of this series. Good films were obtained after the removal of one film by means of acetic acid when the process was repeated without further polishing. Films obtained on the heavy flint were not so good as those obtained on the light flint glasses. They tended to be uneven.

Zinc crown glass. On this glass fairly good films were obtained after taking the precaution of cleaning in alcohol and wiping with a cloth before washing in distilled water. Next to the light flint glasses this zinc glass was the most suitable to use.

Quartz. The polished surface was cleaned in the same way as for glasses. It was found impossible to deposit a film which would adhere to the quartz surface. There was practically no definite film except in a few small faint patches. The rest was a scum of lead sulphide easily washed away by running water.

Boro-silicate glass. This behaved very similarly to quartz, only partial thin films, very uneven in texture, being obtainable.

General Conclusions

From a consideration of the results given above it would appear that, for the deposition of good and even films of lead sulphide by the process prescribed, it is advisable to use either a light flint glass or a zinc crown glass, both of which may be described as reactive towards lead sulphide or to other sulphides produced in the solutions during the process. The deposition of a film of lead sulphide on the glass and its adherence thereto would be favoured by the kind of chemical attraction indicated. With the ordinary sodium-calcium glasses their reaction with sulphur compounds will not be to give insoluble compounds on their surfaces so readily as the lead and zinc glasses do and, as has been mentioned, the films on the sodium-calcium glasses were uneven and could not be controlled.

The boro-silicate glasses which were unusable for this process are acid glasses, and on their surfaces there is but little attraction for the sulphur compounds under consideration. There was even greater evidence of lack of attraction for sulphur compounds in the case of quartz, on the surface of which it was practically impossible to deposit any film of lead sulphide.

It would appear as if the dense flint glasses should, on the suggestions, give even better results than the light flint. The film was readily formed on these glasses, but tended to be uneven, and the unevenness may be ascribed, perhaps, to the greater tendency of some part of the lead oxide in the surface of the glass rapidly to remove sulphur compounds from the solution and to produce a mottled effect by giving varying thicknesses of lead sulphide on the glass.

LABORATORY AND WORKSHOP NOTES

GOOD AND BAD SCREWS. By B. BROWN, B.Sc. (Eng.)

In all classes of mechanical work the quality of fit between two mating parts is of the highest importance. With the shaft and hole the question is comparatively simple, but with screw threads there exists a certain amount of confused thought.

In the first place it will be well to make a comparison between the functions of the component parts of both a plain and screwed pair. The amount of allowance between a shaft and a hole, whether negative or positive, caters for a frictional effect. If the hole is made smaller than the shaft as in shrunk work it is to enable great contractile forces to come into being so that the pair will be firmly gripped together—a phenomenon illustrating the so-called laws of friction. Where the shaft and hole form an ordinary turning couple, the allowance again enters into the question having regard to the frictional effect of the film of lubricant. In the case of the screw pair the case is quite different for the axial load is carried by the actual flanks of the threads. Of course friction plays its part, but the helix angle is usually so small that failure by reversal is impossible except where there is repeated vibration.

Put briefly the actual tolerance of plain fits must be relatively small since the functioning of the whole device depends upon the presence or absence of friction. Clearly the fit must

not be so slack as to render the thing useless. With the screw the tolerance may be large, the only conditions to be satisfied being that the parts must assemble and that there must be sufficient flank contact for strength.

There appears to be a mistaken idea prevalent about the fit of a good screw. It is thought that if a screw fits into a ring gauge without shake the screw is good. On the contrary, with ordinary production work, if a screw does not rattle in the ring, depend upon it that there is something amiss with one or other of the elements. Providing that all the elements of a screw and nut are made in the correct ratio it is almost impossible to produce them so that they will assemble without there being a trace of shake. This statement includes gauge work.

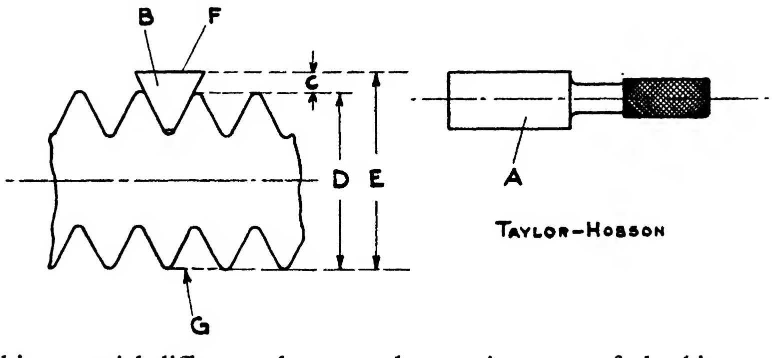
The ordinary full form screw ring and plug are practically useless for production gauging though they are still used extensively. Providing that the gauges are made properly the work passed by them should be interchangeable. This latter property is of little value if there is no control of the strength. Nearly all screws and nuts are stressed to a high degree, though this fact is not always appreciated.

It is not our present purpose to go into the question as to how a proper size control should be exercised. What we wish to point out is that a screw should not be expected to assemble without shake. In some instrument work where a smooth motion is imperative the screw is actually made oversize, and when it is put through the nut part for the first time plastic flow of the metal takes place. The above remarks deal only with the screw and nut used simply as fastenings and not as a means of transmitting motion.

V-PIECE FOR GAUGING THE SLOPES OF SCREW THREADS

When some thirty-five years ago Mr W. Taylor devised the needles and prisms which, through the work of the National Physical Laboratory, became very generally known during the war for the measurement of screw gauges, he devised another prism, not so well known, which is specially adapted for gauging the threads on the work itself.

This V-piece is shown at "A" in the accompanying illustration, and an end view of it is shown at "B" between two adjacent slopes of a screw thread.



There is this essential difference between the requirements of checking any gauge and checking the work itself. In a gauge we must ensure that no part has a deficiency of material, while in the work itself we have to ensure that no part has a surplus.

Accordingly the present gauge is so formed that it bears against the whole of the thread slopes, but is truncated in section so that it clears the root of the thread. It is conveniently made so that the distance "C," by which the gauge stands above the crest of a normal thread, is some simple constant, for example, ·1000″. In use the V-piece is put with the screw between the jaws of a measuring machine or micrometer and the distance "E" is measured. The V-piece is then withdrawn without moving the screw and the full diameter

of the screw "D" is taken. If the full diameter and that of the slopes are normal, the difference between the two measures "D" and "E" is equal to "c" the constant of the V-piece. And when this is so the form of thread is so far correct.

The jaws of the measuring machine square up the V-piece so that it takes account of uprightness of the thread; a factor which, of course, affects interchangeability but which is not taken into account when needles alone are used to gauge the slopes.

It may be objected that this gauge does not gauge the screw in an axial plane, and that the plane surfaces of the gauge cannot bear uniformly down the slopes of a perfect thread, because the thread surfaces are helicoidal. While this objection does apply to screws of relatively coarse pitch, the point is academic so far as concerns ordinary constructional screws and totally insignificant in connexion with the screw threads of lens mountings, for which trigonometrical measurement of screw threads by means of needles and prisms was originated.

THE TAYLOR-HOBSON RESEARCH LABORATORY, LEICESTER.

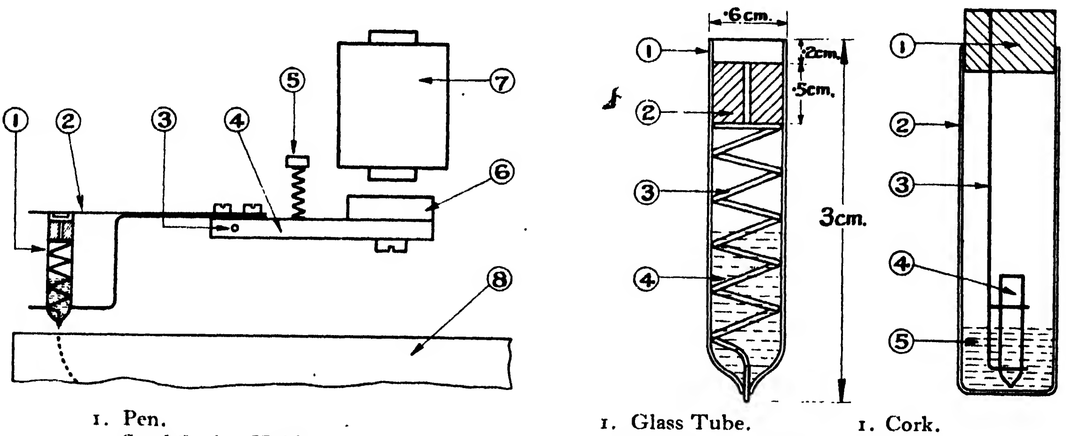
A PEN FOR AUTOGRAPHIC RECORDING*.

By DARTREY LEWIS, M.Met.

[*MS. received 4th December*, 1926.]

As difficulty is often experienced in obtaining a satisfactory pen for autographic recording it may be of interest to describe one which has been developed for use with the "Rosenhain plotting chronograph"† and has proved entirely satisfactory in use.

The detail of the pen is shown in the centre of the diagram. The glass tube should be drawn down until, when the capillary has been suitably cut off, the hole is slightly too small for the wire. The tube should then be ground back with fine emery paper until the wire slides easily in the hole but does not show any side play. The spiral should be of such



1. Pen.
2. Steel Spring Holder.
3. Horizontal Pivot.
4. Brass Arm.
5. Spiral Spring.
6. Steel Armature.
7. Electromagnet.
8. Revolving Drum carrying Record.

1. Glass Tube.
2. Rubber Stop with Centre Hole.
3. Spiral of 12 Carat Gold Wire 0·015 dia.
4. Ink.

1. Cork.
2. Glass Specimen Tube.
3. Nickel Chromium Wire Holder.
4. Pen.
5. Ink.

Pen for Autographic Recording

* Communication from the Research Department, Woolwich.

† Made by the Cambridge Instrument Co., Ltd.

a size that it is held in position by the rubber plug and the shoulder of the tube and should be cut off with a projection of about $\frac{1}{2}$ mm. On striking the paper the wire moves in the hole and maintains a clean ink way.

In use the pen is mounted in a spring holder and operated by a tapping key actuating an electromagnet as shown in the left diagram. The clearance between the pen and paper should be adjusted so that the pen only hits the paper by virtue of its momentum and so does not remain in contact with it when the tapping key is held down.

The pen should be stored in its ink in the way shown at the right of the diagram, and the ink should not be allowed to dry on the pen, otherwise difficulty may be experienced in cleaning it. Aqueous solutions of magenta and analine blue make satisfactory red and blue inks, and the pen is filled by sucking in the ink through the point by means of a rubber tube attached to the top. A full pen will record about 1500 dots.

Two of these pens have been quite reliable when in regular use for over a year. They were always ready for use, did not require cleaning, and produced uniformly good records at all times.

PHYSICS IN NAVIGATION

The eleventh of the series of lectures on Physics in Industry arranged by the Institute of Physics was delivered by Dr F. E. Smith, C.B., C.B.E., D.Sc., F.R.S., at the Institution of Civil Engineers on the 8th December last, under the Chairmanship of Sir William Bragg.

Dr Smith began his lecture with a review of the history of the art of navigation, and found it useless to search antiquity for physicists devoted to the study of navigation. May be philosophers rarely went to sea. The work of the experimentalists Galileo and Gilbert had however considerable effect in advancing the science. The accurate measurement of Latitude was made possible by Hadley's invention of the sextant in the 18th century, and the determination of Longitude with similar exactitude followed Harrison's invention of the chronometer. Unfortunately celestial objects are not always visible, and even if they were, instruments are needed for keeping a ship on a predetermined course, for recording speed and for use during fog. In this direction the physicist in modern times has been remarkably successful.

The first navigational instrument was the mariner's compass which was a great aid to the navigator long before its principles were understood, and even with the growth of knowledge of magnetic phenomena, improvements in the compass were poor and slow. From the 13th century to the time of Kelvin the only innovations of importance were the introduction of gimbals in the 16th century and an increase in the number of magnets used in the 19th century.

Lord Kelvin brought the magnetic compass practically to its present state of perfection, but the effects of iron and steel in ship construction introduced fresh difficulties which were largely overcome by the researches of Archibald Smith, although the magnetism of a ship is liable to change so that no magnetic compass can be relied on for too long an interval.

This defect is of course pre-eminently shown in submarines, and led to the development of the gyroscopic compass which depends for its action on gravitation and the rotation of the earth. It follows from Newton's first law of motion that a heavy mass such as a gyro wheel, even if not spinning, tends to maintain its orientation in space, and only moves because of gravitational and frictional forces. The effect of rapidly spinning the wheel is equivalent to endowing it with a much greater inertia, and a larger value of the time-integral of any disturbances is required to produce a given angular displacement. Gyro compasses have been applied to the automatic steering machine and to automatic course plotters, which trace the course of a ship by the combined action of the gyro compass and the log.

The various forms of logs were described: the early log of wood which was thrown overboard and timed; the rotating vane devised by Dr Hooke in the 17th century and shown to the Royal Society; a water pressure log invented in 1807. The screw form is now most generally adopted. Details were given of the various methods of depth sounding from the old lead and line to the Kelvin sounding apparatus in which a sinker was attached to a length of piano wire and enclosed a glass tube, the interior surface of which was coated with chromate of silver. As one end of the tube was closed, the air contained in it was compressed proportionately to the depth, and the salt water in the tube reduced the orange silver chromate to white silver chloride, the depth therefore being indicated by the position of the dividing line.

A considerable amount of investigation and a fair amount of application of echo depth sounding have taken place recently. A sound is made by striking a plate in contact with the ship's bottom and the time-interval between the emission of the sound and the reception of the echo from the bottom is measured and gives the depth from the velocity of sound in sea water. The Admiralty type of depth sounding gear was described; this apparatus has given accurate results from a few feet to two or three miles.

Turning to methods for determining the ship's position in fog, the Acoustic and Radio-Acoustic methods of location were described, and also the various applications of directional wireless navigation which have not only assisted the finding of positions and steering a definite course but have greatly contributed to our knowledge of the differences between day and night transmission and the effect of the earth's magnetic field in rotating the plane of polarization and causing double refraction in wireless transmission.

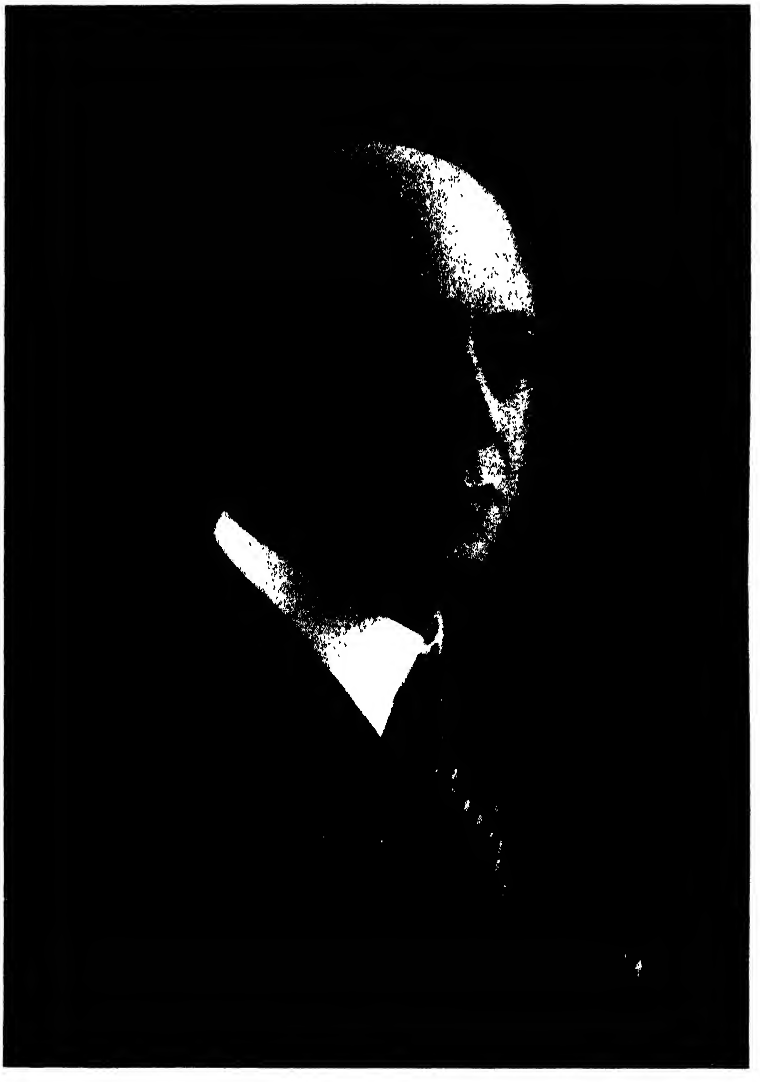
For facilitating the entry to harbours in fog, Leader Gear was devised to enable a ship to follow the course of an insulated cable supplied with alternating current of sonic frequency. The ship carries search coils on each side which can be connected to telephones through an amplifier and indicate the position of the cable by the relative strengths of the signals on the two coils. This system is very successful but costly, and is at present in operation at Portsmouth and in the Ambrose Channel, New York.

While the physicist and engineer have achieved much in these directions they have been less successful in aiding navigation in the ice fields. Many suggestions have been made to detect icebergs by echoes either in air or water, but it has been found that these echoes are not always present and that when they are obtained they frequently give illusory indications. A more promising method depends on the change in the sea temperature near an iceberg, but at present the chief safeguard against ice in the North Atlantic is an international patrol service of two vessels which transmit warnings by wireless to ships in or near the ice zone.

AWARD OF THE DUDDELL MEDAL

The Council of the Physical Society, at its meeting on Dec. 10, 1926, awarded the Fourth Duddell Medal for meritorious work on scientific instruments and materials to Mr F. Twyman, F.R.S. The firm of Adam Hilger, Ltd., of which Mr Twyman has for many years been both managing and technical director, enjoys, and enjoys deservedly, a reputation for the production of optical instruments employed in physical research which is not approached by that of any other firm in this or any other country. To quite a remarkable extent the fundamental researches which have led to the formation of the current conceptions of the nature of matter have been carried out with the aid of instruments of the necessary high degree of precision constructed in the Hilger workshops. The production of these instruments has frequently involved the solution of problems which have only been met successfully through Mr Twyman's persistence and resourcefulness.

In addition to the services rendered to the cause of pure science, Mr Twyman has carried out notable work on a number of technical problems. Two may be specially mentioned. His investigations on the annealing of glass (which incidentally led to "Twyman's Law" on the influence of temperature upon the mobility of the melt) are of fundamental importance, and his instruments for controlling this operation have been of service to all branches of the glass-making industry. These investigations have been an important factor in securing



Mr F. Twyman, F.R.S.

home supplies of reliable glass-ware for scientific purposes. Moreover, during the war, they led to a notable increase in the output of optical glass, by substituting for the traditional routine a novel scheme of annealing, which, without any deterioration in the quality of the product, enabled the time occupied in this operation to be greatly reduced.

As another example of technical work, the extensive series of Hilger Interferometers may be mentioned. The Michelson type of interferometer has been modified and adapted to a large number of special uses of interest to the optical industry. By the use of these instruments accurate measurements can now be made of the defects of all manner of optical

parts and instruments, whether these defects are due to faulty design, imperfect workmanship or defective material. It is characteristic of Mr Twyman that these new instruments were immediately used not merely to measure the defects, but also as a means of removing them.

INSTITUTE OF PHYSICS

THE resignation of Professor A. W. Porter from the Honorary Secretaryship of the Institute of Physics was recently received by the Board of the Institute, and was accepted with great regret. Professor Porter has been associated with the Institute from its inception, and its growth is largely due to his efforts. Professor A. O. Rankine, of the Imperial College of Science, has been appointed his successor.

Mr Thomas Martin, M.Sc., D.I.C., who has recently held the positions of Secretary of the British Empire Exhibition Committee of the Royal Society and of the Optical Convention, 1926, has been appointed Secretary to the Institute. He succeeds Mr G. S. W. Marlow, who has been Acting Secretary since the death of Mr F. S. Spiers.

The Office of the Institute of Physics has been transferred from 90 Great Russell Street to 1 Lowther Gardens, Exhibition Road, London, S.W. 7, and all communications should now be sent to the new address. A tenancy of the premises to be occupied at 1 Lowther Gardens has been granted to the Institute, on very generous terms, by the Royal Commissioners of 1851; and the Commissioners, in placing this spacious accommodation at the disposal of the Institute, are giving great assistance to its work and to that of its participating societies.

The office of the *Journal of Scientific Instruments* will also be at 1 Lowther Gardens, and all Editorial communications should be sent there in future.

SEVENTEENTH EXHIBITION OF SCIENTIFIC INSTRUMENTS

THE Seventeenth Joint Exhibition of the Physical and Optical Societies was held at the Imperial College, South Kensington, on January 4, 5 and 6, and was of the greatest interest. Probably the most novel and attractive feature was the lecture by Prof. E. N. da C. Andrade, as it might have been given by Hauksbee in 1709, in the language and costume of the period and using the original air pump kindly lent by the Royal Society, and a replica of his electrical machine specially constructed by Mr R. W. Paul. The February issue of the *Journal* will be enlarged, and will contain the lectures and critical descriptions of the exhibits.

TABULAR INFORMATION ON SCIENTIFIC INSTRUMENTS

XVI. SPECTROMETERS, SPECTROSCOPES, AND SPECTROGRAPHS

THE annexed table gives particulars of various forms of Spectrometers, Spectroscopes, and Spectrographs, as furnished by their respective manufacturers. A copy of this table can be obtained by any subscriber on application to the Secretary of the Institute of Physics, 1 Lowther Gardens, Exhibition Road, London, S.W. 7; and bound copies of the twelve tables which appeared in the last volume can be obtained from the same source, price 3*s*. 6*d*. post free.

XVI. SPECTROMETERS AND SPECTROSCOPES

Type	Catalogue No.	Diameter of circle	Reading to	Approximate angular dispersion*	Diameter of O.G. (mm.)	Magnification	Remarks	List price
Maker:—MESSRS R. & J. BECK, LTD., 69 MORTIMER STREET, W. 1.								£ s. d.
Diffraction grating	2444	—	—	20°	—	—	Fixed slit. Pocket direct vision	1 3 0
Diffraction grating	2425	—	—	34°	—	—	Adjustable slit. Reading in wave-lengths on drum to an arbitrary scale of 100 divisions. Direct vision	5 5 0
Diffraction grating	3500	—	10 A.U.	30° to 50°	·7	Variable	Adjustable slit. Reading in wave-lengths on drum	Price under revision
Diffraction grating	2440	—	—	—	·7	Variable	Sun prominence spectroscope with curved slit—adjustable slit	20 0 0
Quartz lenses and prisms for ultra-violet	2435	—	Wave-length scale div. 100 A	20°	—	—	Ultra-violet fluorescent screen and wave-length scale	6 17 6
Maker:—MESSRS BELLINGHAM & STANLEY, LTD., HORNSEY RISE, N. 19.								
Single prism or grating	S 1	15 cm.	1 min.	Depends on the glass selected for the prism	2 cm.	10–15	For students' use, to demonstrate the more important experiments in spectroscopy	12 0 0
Single or multiple prism or grating	S 2	3·8 cm.	20 sec.	—	3·8 cm.	10–20	For accurate angle measurement. Refractive index determination and general spectrometric investigations	55 0 0
Single or multiple prism or grating	S 3	20 cm.	30 sec.	—	2·5 cm.	10–20	Auto-collimating spectrometer	55 0 0
Single or multiple prism or grating	S 4	20 cm.	10 sec.	-	3·0 cm.	10–20	Auto-collimating spectrometer	140 0 0
Solar spectroscope with two prisms	S 5	—	Reading by micrometer screw	—	1·9 cm.	15	For the examination of solar prominences	85 0 0
Solar spectroscope with three prisms and/or grating	S 6	—	Reading by micrometer screw	Dispersion sufficient to separate 1/10 A	11 cm.	—	For sunspot investigation or for the examination of solar prominences	425 0 0
Single prism 30° constant deviation	S 7	Direct reading in wave-lengths	—	—	3·2 cm.	—	For wave-length measurements throughout the spectrum between the limits of 1850 A and 150,000 A with interchangeable mirrors and prisms	For the visible spectrum 50 0 0 Additions extra
Constant deviation prism	S 8	Direct reading in wave-lengths	—	—	2·2 cm.	—	With tilting adjustment, for use vertical or horizontal	30 0 0
Constant deviation	S 9	Reading by micrometer screw	—	—	1·3 cm.	10	For use with microscope	19 10 0
Constant deviation	S 10	Reading by micrometer screw	—	—	1·3 cm.	10	Hartridge reversion type, for use with microscope	24 7 6
Constant deviation 300 prism	S 11	Wave-length scale reading	20 A	—	1·7 F 5	4	Quartz train for use in the ultra-violet	6 10 0
Direct vision compound prism	S 12	—	—	—	1 cm.	8	With 9 cm. long fixed or adjustable slit for hand use	1 18 6 2 8 6
Direct vision compound prism	S 13	Reading by micrometer screw	—	—	1·3 cm.	10	20 cm. long	12 0 0
Makers:—MESSRS J. J. GRIFFIN & SONS, LTD., & BAIRD & TATLOCK, LTD., KEMBLE STREET, KINGSWAY, LONDON, and at GLASGOW, MANCHESTER, EDINBURGH and LIVERPOOL.								£ s. d.
Single prism	X 4161	5″	1 min.	1° 57′	1″	7·5	Designed to give rigid support to telescope and collimator; fitted with comparison prism, fine adjustment for slit, prism table, telescope and cross wires. Polariser and analyser, Babinet compensator and quarter wave plate can be supplied to fit instrument	35 0 0
Ditto	X 4153	5″	1 min.	1° 20′	$\frac{7}{8}$″	5	Fine adjustment for telescope and prism table. Comparison prism fitting can be supplied	16 0 0
Single prism. Chemical spectroscope	X 4130	No graduated circle		—	—	-	Adjustable slit, fixed prism fitted with 3rd tube carrying photographic scale for comparison	7 10 0
Ditto	X 4132	—	—	—	—	—	Without 3rd tube	5 10 0
Direct vision spectroscope, pocket size	X 4144	—	—	6°	—	—	3½ in. long. Plain slit	1 12 6
Ditto (with adjustable slit)	X 4146	—	—	6°	—	—	Adjustable slit	2 7 6
Rainband spectroscope	X 4150	—	—	7°	—	—	5 in. long. Adjustable slit, rack and pinion focussing	5 5 0

* The angle required is the angle between the C and G' lines between the prism and the telescope when the instrument is arranged so that D is in minimum deviation. For direct spectroscopes the angular dispersion refers to the angle *at the eye* between the C and G' lines.

Type	Catalogue No.	Diameter of circle	Reading to	Approximate angular dispersion*	Diameter of O.G. (mm.)	Magnification	Remarks	List price £	s.	d.
Maker:—MESSRS ADAM HILGER, LTD., 24 ROCHESTER PLACE, N.W. 1.										
Educational spectrometer	C 14	5½″	1 min.	2° 35′	17	12	Including 60° prism	12	10	0
Table spectrometer	C 1	6″	1 min.	3° 13′	31·5	11·3	,, ,,	35	0	0
Table spectrometer	C 7	8″	30 sec.	3° 13′	31·5	9 and 18	,, ,,	59	0	0
Table spectrometer	C 12	10″	Table 30 sec. Telescope 1 sec.	2° 35′	41·5	11·6; 19; 36	Three eyepieces with separate cross webs supplied. Microscopes with micrometer eyepieces for reading circle	427	0	0
Wave-length spectrometer (constant deviation type)	D 1	None	1–3 A	2° 48′	31·5	15	With prism of light flint glass. Reading in wave-lengths direct on drum	50	0	0
Ditto	D 2	,,	,,	5° 11′	31·5	15	With prism of dense flint glass	50	0	0
Ditto	D 57	,,	,,	2° 48′	31·5	15	Improved design, 1926 model. With light flint glass prism	57	0	0
Ditto	D 66	,,	,,	5° 11′	31·5	15	Improved design, 1926 model. With dense flint glass prism	57	0	0
Ditto	D 19	,,	1 A	2° 48′	41·5	19	Large direct reading instrument	181	0	0
Ditto. Small model for students	D 45	,,	1–3 A	2° 48′	17	12	A smaller model of the standard instrument employing a similar drum and scale. With light prism	33	0	0
Wave-length spectrometer	D 50	,,	,,	5° 11′	17	12	With dense glass prism	34	5	0
Ditto. With diffraction grating	D 25	,,	1 A	8° 30′	31·5	15	Reading wave-lengths direct. Employs replica grating on glass prism	68	10	0
Chemical spectrometer	D 39	,,	1½ A	5° 11′	—	12	An auto-collimating spectrometer specially designed for chemical laboratories	40	0	0
Flame wave-length spectrometer	D 48	,,	10 A	2° 35′	17	3·8	Photoscale divided in wave-lengths	26	10	0
Ditto	D 49	,,	10 A	,,	,,	,,	As above, but with telescope, collimator, etc. in a vertical plane	28	10	0
Dr Tutton's spectroscopic monochromatic illuminator	D 32	,,	1·5 A	2° 50′	31·5	9·7	For crystallography, etc. Uses a constant deviation prism and has an aperture ratio of F/6	106	0	0
Spectrometer and monochromatic illuminator for the ultra-violet and visible	D 33	,,	3 A	1° 5′	31	4	Uses a constant deviation system of a mirror and prism of quartz. Calibrated in wave-lengths from 1850 to 9000 A	138	0	0
Ditto	D 41	,,	3 A	,,	—	4	As above, but working at F/4·5	250	0	0
Infra-red spectrometer	D 35	,,	—	2° 15′	38	5	Uses a prism and mirror constant deviation system. Prism of rocksalt. Fitted with linear thermopile. Calibrated from 3800 to 100,000 A	117	0	0
Ditto	D 42	,,	—	,,	50	5	As above, but working at F/4·5. Calibration extends from 0·38μ to 16μ	160	0	0
Simple ultra-violet spectroscope	E 69	,,	10 A	—	—	—	Quartz optical train. Spectrum shown on a fluorescent screen. Has a wave-length scale	23	10	0
Echelon spectroscope	B 29	—	—	—	31·5	22·5	For 10 to 14 plates 10 mm. thick	45	7	6
Ditto	B 32	—	—	—	41·5	14½ & 29	,, 15 ,, 20 ,, ,,	96	5	0
Ditto	B 35	—	—	—	51	22 & 44	,, 21 ,, 33 ,, ,,	147	2	6
Ditto	B 38	—	—	—	51	22 & 55	,, 34 ,, 40 ,, ,,	177	7	6
Ditto	B 229	—	—	—	51	15, 29 & 55	,, 41 ,, 56 ,, ,,			
Ditto	B 43	—	—	—	As B 29	15 & 35	Arranged to take échelon. Horizontally complete with constant deviation spectrometer: all on one base	137	10	0
Ditto	B 44	—	—	—	As B 32	14·5 & 29		174	12	6
Ditto	B 45	—	—	—	As B 35	22 & 55		258	10	0
Ditto	B 46	—	—	—	As B 38	22 & 55		290	2	6
Ditto	B 231	—	—	—	As B 229	22 & 55				
Ditto	B 48	—	—	—	As B 29	15 & 35	As above, but to take échelons in a different manner	98	0	0
Ditto	B 49	—	—	—	As B 32	14·5 & 29		187	0	0
Ditto	B 50	—	—	—	As B 35	22 & 55	Ditto	405	12	6
Ditto	B 51	—	—	—	As B 38	15, 29, 44	Ditto	459	5	0
Ditto	B 232	—	—	—	As B 229	15, 29, 55	Ditto	500	0	0
High resolving power spectrometer	O 8	None	1·5 A	—	31·5	—	As D 2, but modified to accommodate lummer plate or étalon	87	0	0
Ditto	O 10	,,	1·5 A	—	31·5	—	As O 8, but extended to take 12 plate échelon	98	0	0
Nickel and chromium detecting spectroscope	D 61	A special spectroscope arranged for observations of certain prominent lines in the spectrum so as quickly to identify the presence of nickel and chromium in a sample of metal. Variations of this instrument are also made for the detection of other ingredients of steels						75	0	0
Maker:—E. R. WATTS & SON, 123 CAMBERWELL ROAD, S.E. 5.										
Student's spectrometer	733	7″	1 min.	—	32 mm.	×18	This is a strong, simple instrument for students, provided with a slot and web aperture to collimator	50	0	0
Advanced student's spectrometer	734	7″	5 sec.	—	37 mm.	×30	This instrument follows generally the student's model, but the circle is read by micrometer microscopes and the telescopes are larger and of greater power	87	0	0

* The angle required is the angle between the *C* and *G′* lines between the prism and the telescope when the instrument is arranged so that *D* is in minimum deviation. For direct spectroscopes the angular dispersion refers to the angle *at the eye* between the *C* and *G′* lines.

SPECTROGRAPHS

Type	Catalogue No.	Focal length (cm.)	Length of spectrum (cm.)	Range of wave-lengths ($\mu\mu$)	Diameter of O.G. mm.	Remarks	List price £ s. d.
Maker:—MESSRS BELLINGHAM & STANLEY, LTD., HORNSEY RISE, N. 19.							
Quartz Cornu prism	S 14	30	10	2100 A–8000 A	15	Entire range of spectrum on flat plate. All-metal frame	39 10 0
Quartz Cornu prism	S 15	63	21	2100 A–8000 A	50	Entire range of spectrum on flat plate. All-metal frame	140 0 0
Quartz 30° prism	S 16	200	60	2100 A–8000 A	60	Auto-collimating spectrograph. Spectrum photographed in three sections. All-metal frame	240 0 0
Quartz Cornu prism	S 17	30	10	1830 A–2500 A	15	For investigations near the limit of transmission of air. All-metal frame	39 10 0
Glass or ultra-violet glass 60° prism	S 18	35 cm. of camera lens	Depends on the glass selected for prism	3150 A–8000 A	25	For obtaining a spectrum of high dispersion over the visible and ultra-violet region to 3150 A	
Maker:—MESSRS ADAM HILGER, LTD., 24 ROCHESTER PLACE, N.W. 1.							
Quartz spectrographs	E 1	170	67 (200–800)	193 to 800	70	"Littrow" type. Takes spectrum on four plates, 10″ × 4″	292 0 0
Ditto	E 30	170	"	"	—	As E 1, but of smaller aperture	240 0 0
Ditto	E 2	61	20	210 to 800	51	Dispersing system: one Cornu prism	132 0 0
Ditto	E 3	61	20	"	51	As E 2, but with accurate internal wave-length scale	165 0 0
Ditto	E 315	61	24	200 to 800	51	As E 2, but made in metal	241 0 0
Ditto	E 316	61	24	"	51	As E 3, but made in metal	258 0 0
Ditto	E 29	61	20	210 to 800	33	As E 2, but of smaller aperture	109 0 0
Ditto	E 34	61	20	"	33	As E 3, but of smaller aperture	142 0 0
Ditto	E 319	61	24	200 to 800	33	As E 29, but metal throughout	191 0 0
Ditto	E 320	61	24	"	33	As E 34, but metal throughout	219 0 0
Ditto	E 31	20·3	7·5 (200–800)	185 to 800	—	Dispersing system one cornu prism	39 0 0
Ditto	E 37	20·3	7·5 (200–800)	"	—	As E 31, but with accurate internal wave-length scale	57 0 0
Glass spectrographs	E 56	170	35	380 to 800	70	Similar to E 1	262 0 0
Set of parts to change quartz spectrograph into glass spectrograph	E 52	170	35	"	70	To convert E 1 to E 56 at will	40 0 0
Ditto	E 59	170	35	"	—	To convert E 30 similarly	40 0 0
Ditto	E 62	61	16·3	350 to 800	51	To convert E 2, 3, 29 or 34 to glass spectrographs	40 0 0
Uviol glass spectrograph	E 42	61	10·9	300 to 800	51	Specially designed for metallurgy	163 0 0
Ditto	E 43	61	10·9	"	51	As E 42, but with internal wave-length scale	200 10 0
Infra-red spectrograph with glass prism and lenses	E 64	—	17·6	400 to 1400	—	Employs Becquerel phosphoro-photographic method	137 0 0
Spectrographs with interchangeable optical systems, e.g. 1. Eagle mounting grating 2. Littrow mounting quartz prism and lens	E 77	100	23 (800–400)	Extreme violet to 1st ord. 26·00 2nd ord. 1·300 3rd ord. 8·80 4th ord. 6·50 5th ord. 5·30	50	System No. 1. Dark room type	142 0 0
3. Littrow mounting 1 glass prism and lens	E 86	100	38 (800–200)	193 to 800	50	No. 2. "	163 0 0
	E 95	100	21 (400–800)	380 to 800	50	No. 3. "	134 0 0
4. Littrow mounting one 30° and one 60° glass prism and achro. lens	E 104	100	23 (400–800)	350 to 800	50	No. 4. "	164 10 0
	E 113	100	23 (400–800)	350 to 800	50	No. 5. "	164 10 0
	E 78	100	Same as E 77	above	50	No. 1. Hand adjusted type	172 0 0
	E 87	100	" E 86	"	50	No. 2. "	193 0 0
5. Plane grating and achro. lens	E 96	100	" E 95	"	50	No. 3. "	164 0 0
	E 105	100	" E 104	"	50	No. 4. "	194 10 0
	E 114	100	" E 113	"	50	No. 5. "	184 10 0
	E 79	100	" E 77	"	50	No. 1. Screw adjusted type	189 0 0
	E 88	100	" E 86	"	50	No. 2. "	210 0 0
	E 97	100	" E 95	"	50	No. 3. "	181 0 0
	E 106	100	" E 104	"	50	No. 4. "	211 10 0
	E 115	100	" E 113	"	50	No. 5. "	211 10 0
	E 80	150	35 (400–800)	Same as E 77	75	No. 1. Dark room type	180 0 0
	E 89	150	57 (200–800)	" E 86	75	No. 2. "	272 0 0
	E 96	150	32 (400–800)	" E 95	75	No. 3. "	164 0 0
	E 107	150	36 (400–800)	" E 104	75	No. 4. "	244 0 0
	E 116	150	35 (400–800)	" E 113	75	No. 5. "	213 10 0
	E 81	150	Same as E 80	above	75	No. 1. Hand adjusted type	224 0 0
	E 90	150	" E 89	"	75	No. 2. "	316 0 0
	E 99	150	" E 96	"	75	No. 3. "	228 0 0
	E 108	150	" E 107	"	75	No. 4. "	228 0 0
	E 117	150	" E 116	"	75	No. 5. "	257 10 0
	E 82	150	" E 80	"	Grating 5 × 3·5 cm.	No. 1. Screw adjusted type	246 0 0
	E 91	150	" E 89	"	75	No. 2. "	338 0 0
	E 100	150	" E. 96	"	75	No. 3. "	250 0 0
	E 109	150	" E 107	"	75	No. 4. "	310 0 0
	E 118	150	" E 116	"	75	No. 5. "	279 10 0

Type	Catalogue No.	Focal length (cm.)	Length of spectrum (cm.)	Range of wave-lengths (μμ)	Diameter of O.G. mm.	Remarks	List price £	s.	d.
Maker:—Messrs ADAM HILGER, Ltd., 24 Rochester Place, N.W. 1.									
Spectrographs with interchangeable optical systems	E 83	300	69 (400–800)	Same as E 77	Grating 8 × 5·0 cm.	System No. 1. Dark room type	236	10	0
	E 92	300	114 (200–800)	,, E 86	75	,, No. 2. ,,	311	0	0
	E 101	300	64 (400–800)	,, E 95	75	,, No. 3. ,,	251	0	0
	E 110	300	70 (400–800)	,, E 104	100	,, No. 4. ,,	363	0	0
	E 119	300	69 (400–800)	,, E 113	100	,, No. 5. ,,	283	10	0
	E 84	300	Same as E 83		100	,, No. 1. Hand adjusted type	302	10	0
	E 93	300	,, E 92		100	,, No. 2. ,,	377	0	0
	E 102	300	,, E 101		100	,, No. 3. ,,	317	0	0
	E 111	300	,, E 110		100	,, No. 4. ,,	363	0	0
	E 120	300	,, E 119		100	,, No. 5. ,,	283	10	0
	E 85	300	,, E 83		100	,, No. 1. Screw adjusted type	328	10	0
	E 94	300	,, E 92		100	,, No. 2. ,,	403	0	0
	E 103	300	,, E 101		100	,, No. 3. ,,	343	0	0
	E 112	300	,, E 110		100	,, No. 4. ,,	455	0	0
	E 121	300	,, E 119		100	,, No. 5. ,,	375	0	0
Grating spectrographs. Eagle mounting	E 18	650	229	200 to 800	150	—	585	0	0
Stigmatic mounting	E 49	300	—	—	—	As used by Meggers and Burns	475	0	0
Vacuum grating spectrograph	E 50	100	—	Down to 360 A	70	Employs two slits to cover 210 to 50μμ	220	0	0
Ditto	E 47	200	—	,,	,,	—	275	0	0
Large aperture two-prism glass spectrographs	E 328 E 328	50	10·1	350 to 800	115	Working aperture *f* 3·5. Dispersing system two 55° dense glass prisms			
Ultra-violet stellar spectrograph	E 329 E 200	20 20	5 5	300 to 800 300 to 800	40	Angular aperture of optical system *f* 5. Dispersing system two 60° Uviol glass prisms	194	0	0
Ditto	E 337	20	5	,,	40	As E 329 with table stand, but without following telescope	184	0	0
Quartz stellar spectroscope	E 338	20	- -	—	40	With viewing telescope	252	0	0
Ditto	E 339	20	—	—	40	As E 339 with table stand, but without following telescope	242	0	0
Stellar spectrograph. Plaskett; with ultra-violet glass train	E 340	20	5	300 to 800	40	Inclined slit jaws reflect image into viewing telescope. Alternative viewing telescope. Special mounting and temperature casing. Twin comparison prisms			
Ditto. With quartz optical train	E 342	20	—	—	40	Ditto			
Ultra-violet glass spectrograph. Harvard form	E 345	20	2	360 to 700	50	Arranged to take two cameras of alternative forms working at *f* 4 and *f* 12. Supplied with *f* 4 camera only			
f 12 camera for above	E 359	60	7	360 to 700	50	—			
Quartz stellar spectrograph. Harvard form	E 346	20	—	—	50	As E 345, but with quartz train, complete with *f* 4 camera only			
f 12 camera for above	E 360	60	—	—	50	—			
Large aperture, large dispersion glass spectrograph	E 349	—	22·9	385 to 800	127	Dispersing system one 60° and one 30° prism equivalent to three 60° prisms. Working at *f* 7			
25 ft. focus glass prism spectrograph	E 347	760	114 (C to G)	380 to 800	—	Dispersing system two 60° and one 30° prism of dense flint glass. Specially designed for remote (electrical) control of prism and lens system. Camera arranged to be built into a wall			
25 ft. focus quartz prism spectrograph	E 348	760	—	—	114	Similar to E 347, but with quartz optical train			
Quartz spectrographs for investigations of fluorescence	E 350	61	20	210 to 800	51	A quartz spectrograph similar to the E 3 model with a supplementary lens whereby the fluorescence produced by the spectrum in the substance to be examined can be photographed in a camera	283	0	0
Attachment to E 3 type spectrograph for fluorescence investigation	E 351	—	—	—	—	—	60	0	0
Fluorite vacuum spectrograph	E 353	13 (1700 A)	10·8	135 to 210	25·4	Dispersing system one 60° fluorite prism. As designed for Prof. J. C. McLennan			
Ditto. With table stand	E 354	—	10·8	135 to 210	25·4	As above			
Muller X-ray spectrograph	E 45/6	Can be employed for the Bragg method, Hull method, or Debye powder method					52	0	0
Ditto	E 334	Similar to E 45/6, but with more refined adjustments and design					64	0	0
Ditto	E 60	Similar to E 45/6, but with additional goniometer and accessories for obtaining Laue and Schiebold photographs					90	0	0
Ditto	E 336	Similar to E 60, but embodying many refinements in construction enabling more precise work to be accomplished					128	0	0

JOURNAL OF SCIENTIFIC INSTRUMENTS

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THE SEVENTEENTH ANNUAL EXHIBITION OF THE PHYSICAL AND OPTICAL SOCIETIES

WITH each succeeding year the Exhibition of Instruments and Research Apparatus organized by the Physical and Optical Societies has grown in interest and importance, and it is probably fair to claim that it is now greatly in advance of any similar display in the world. The exhibition which was held on January 4, 5, and 6 of this year at the Imperial College of Science and Technology, South Kensington, was a notable advance on all its predecessors, chiefly perhaps as regards the Research Section, which was a new departure last year, and has now begun to take vigorous root. A further novelty was introduced this year in a section devoted to lecture experiments in Physics, which attracted considerable attention; and it is to be hoped that it will also grow in scope and be a source of inspiration to teachers, especially if it is supplemented by exhibits by manufacturers of educational apparatus as distinct from the more highly refined testing and research instruments.

The general impression given by the exhibition was that the British Scientific Instrument Industry is in a remarkably healthy and progressive state, especially considering the recent depressing period; and that there has been distinct advance in every direction—novelty, design, and sound and accurate construction. Part of this no doubt arises from the impetus given by the various research departments, but there is also evidence that the manufacturers are engaging a much higher class of scientific assistants and designers than in the past, and that they are having considerable influence upon development.

Considerable interest was also evoked by the three lectures which were given at this year's exhibition, notably by that of Professor Andrade in the character of Hauksbee and in the costume and language of the early eighteenth century; and with his original air pump and other apparatus, made by Mr R. W. Paul to the original designs. The practical aspect of the occasion was developed by Dr Drysdale in his lecture on "Progress in the Design and Construction of Electrical Instruments"; and Mr Baird's lecture on "Television" attracted large audiences, although some disappointment was felt that no actual demonstrations were shown.

Two of the lectures are reproduced in this issue, followed by descriptions of the various sections of the exhibition by specialists who kindly undertook their inspection*, and to whom our thanks are cordially tendered. It is hoped that these descriptions will enable those who were unable to visit the exhibition to gain some idea of the progress which has been made, and assist them, in conjunction with the catalogue, in selecting instruments for their special needs.

It only remains to congratulate Dr Rankine and the other organizers of the exhibition on the remarkable success of their labours, and upon the highly valuable catalogue they have compiled.

EDITOR.

* Dr Drysdale's lecture, and certain of the exhibition descriptions, are unavoidably held over to the March issue of the *Journal*.

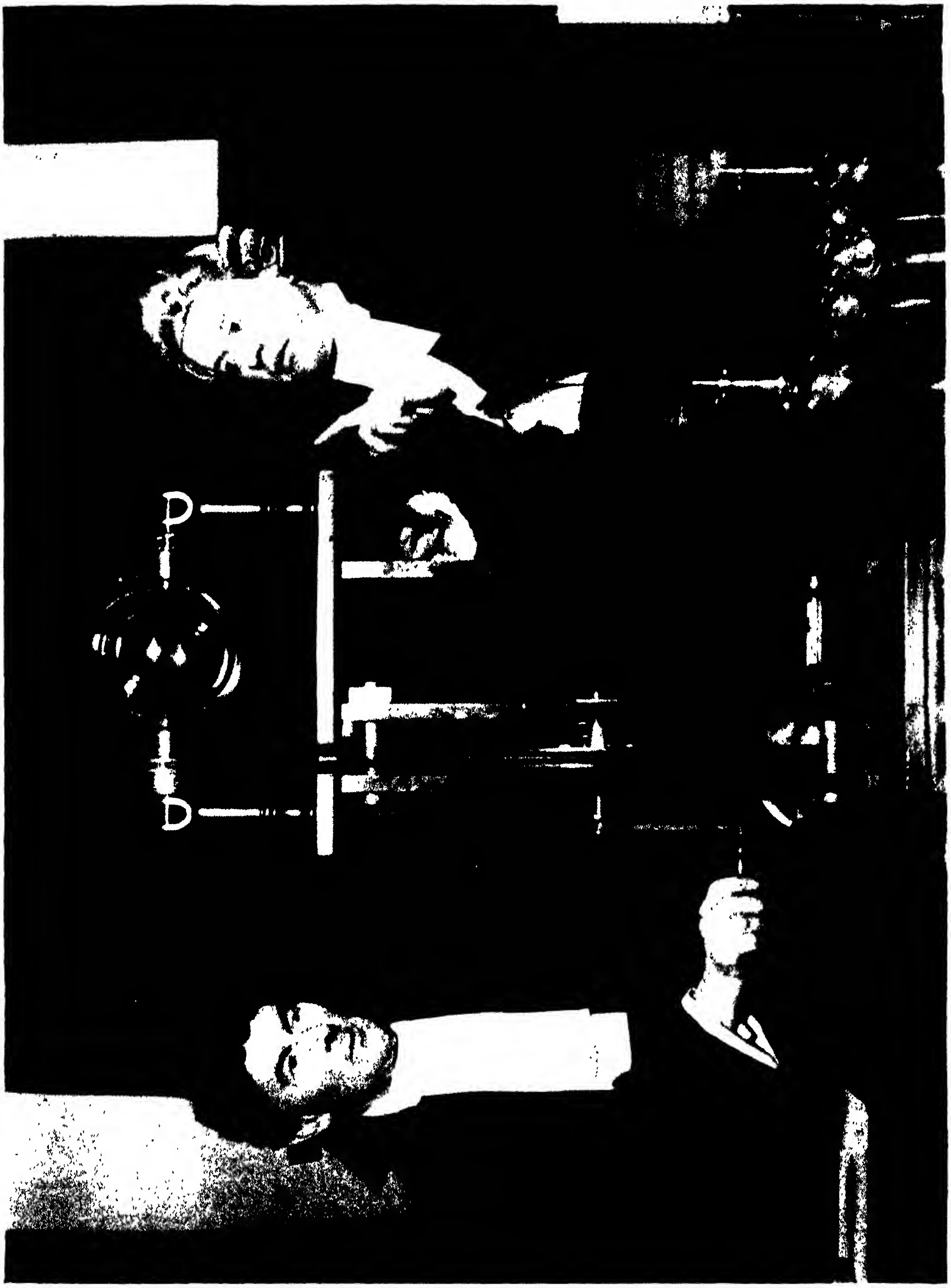
FIRST LECTURE. JANUARY 4TH

A LECTURE WITH EXPERIMENTS ON VARIOUS SUBJECTS GIVING AN ACCOUNT OF SEVERAL SURPRISING *PHENOMENA* TOUCHING *LIGHT* AND *ELECTRICITY*. DELIVERED BY PROF. E. N. DA C. ANDRADE, D.Sc., Ph.D.*

My Lords and Gentlemen (and, I must add last what I should have said first, Ladies, for I rejoice to see that so many of my pretty Country-Women are following the high example of the famous Duchess of Newcastle, and bending their minds to a subject so harmless and free from all dishonesty as Natural Philosophy), I come before you this evening very sensible of the honour which your *Learned Society* has done to so undeserving a person as myself, in permitting me to demonstrate before you divers Novel Experiments concerning the Emission of certain *Kinds of Light* from different bodies. In presenting with all respect the fruits of my *Philosophical Endeavours* to your ingenious Notice, I would observe that the *Learned World* is now almost generally convinced that the only sure way of improving Natural Philosophy is by *Demonstrations* and *Conclusions* founded upon *Experiments* judiciously and accurately made, and that *Vain Hypotheses* and *Fine Argumentations* concerning the nature of Body, Quantity and Motion, if they be not squared to Particular Observations of True Happenings, may give an *Empty Satisfaction*, but serve rather to *swell* than *fill* the Soul, as the learned Dr. Spratt has so justly written in his admirable *History of the Royal Society*. By setting themselves free of the authority of Aristotle, and turning to the right course of *Slow* and *Sure Experimenting*, our *Virtuosi* have in fifty years made more advancement in Real Knowledge than five centuries of Notion and Dispute could effect in the past. I need but instance that by *Experiment* and *Observations* the glory of our age, the most Learned and Incomparable *Sir Isaac Newton*, has advanced that part of *Optics* concerning the Nature of Light and Colours, of which there was little, if anything, known before, to a *Perfect* and *Complete Science*.

Of all Engines which our *New Philosophy* has employed, none has shown itself more useful than the *Air-Pump*. The Royal Society has been most sollicitous in its encouragement of this invention, and by directing *Enquiries* and *Trials* to be made has given occasion for great improvements in this Noble Machine. The Honourable and most Excellent Mr. Boyle, whose death nineteen years ago almost to this day robbed Philosophy of one of her *Choicest Adornments*, first made invention of a tolerably good Pneumatic Engine, although, as he liberally acknowledged, the German von Guericke had prevented him in the creation of a *Vacuous Space*. Nevertheless the German Engine was manifestly imperfect. This original Engine of Mr. Boyle had but one Hollow Cylinder, so that as the air was drawn out of the Recipient it required great strength to ply the Pump, by virtue of the *Great Pressure* of the *Whole Atmosphere* which is not resisted when there is no, or but little, Air beneath the Sucker. Later, the most Excellent Mr. Boyle, aided by the Ingenious Monsieur Papin, devised an Engine which had two Cylinders, to be worked by the Feet, placed for that

* The experiments shown in this lecture were described by Francis Hauksbee, F.R.S., in his *Physico-Mechanical Experiments*, 1709, and the language is such as I suppose he might have used in demonstrating them. (E. N. DA C. A.)



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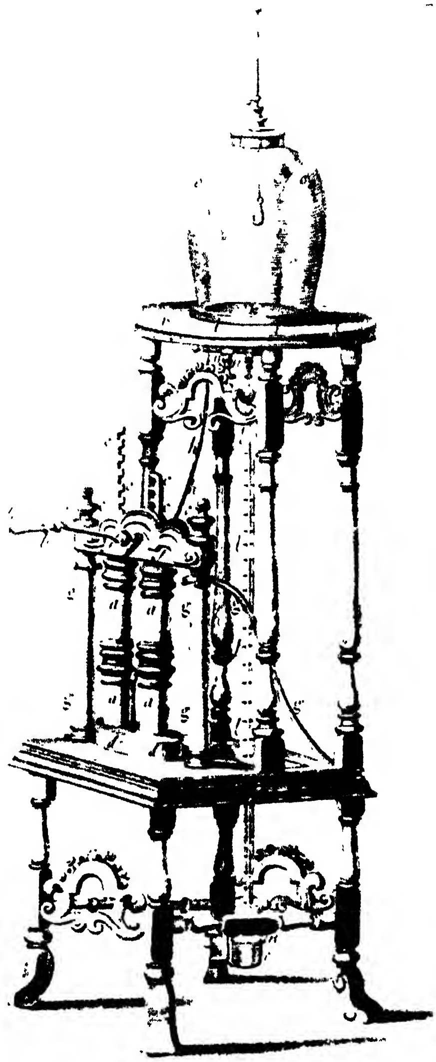
Professor Andrade delivering the Hauksbee lecture (Mr Banfield acting as assistant)

purpose in Stirrups, but it lacked somewhat in convenience of manipulation, nor did the *Noble Experimenter* ever apply it to such *Diversity* of *Trials* as he made with the earlier Engine.



In the improved Air-Pump which I present to you this evening, there are two Barrels or Cylinders as represented by aaaa, twelve inches in height, and some two in diameter within. The Suckers, or *Emboli*, are raised and depressed by turning the Winch bb backwards and forwards. The Winch is fastened to a Spindle that passes through a Lanthorn, whose Pins perform the Office of Cogs, for in its motion they lay hold on the Teeth of the Racks cccc, and so reciprocally as one is depressed the other is elevated. The Valves are made of limber Bladder, and fixed on the upper part of each *Embolus*, as well as at the bottom of the fore-mention'd Cylinders, and as the *Emboli* are set in motion they perform their Offices mutually of exhausting and discharging the same Air taken from the Recipient on the Plate of the Pump. And when the Recipient comes to be pretty well exhausted of its contain'd Air, the pressure of the outward Air on the descending Sucker is nearly so great, that the Power requir'd to raise the other is very little more than what surmounts the friction of the moving Parts, which renders the Pump preferable to all other.

The bottoms of the barrels are plac'd in a Brass Dish, represented by dd, whose sides are about two inches high, and is on purpose to put Water in, to keep the Leather Collars on which the Brass Cylinders stand, moist, whereby the air is prevented from insinuating into the Cylinders in those parts. But by the care of my apprentice Robert Paul, an excellent mechanic, in the Adjustment of the Parts, I have no need of Water this evening. From between the two Brass Barrels arises a brass hollow wire, hhhh, which hath a communication with each of 'em, by means of a perforated piece of Brass which lies along horizontally from one to the other. The upper end of this hollow Wire is fastened to another piece of perforated Brass, which screws on underneath the plate iiii, which is 10 inches over, and has a Brass Rimm to prevent shedding of Water, for which there is occasion in several Experiments. About the middle of the plate arises a small Pipe, k, thro' which and the fore-mentioned hollow wire passes all the Air into the Barrels, as it is taken from the exhausting Receiver. Upon the plate of the pump is always laid a wet Leather on which the Recipients are plac'd: this wet Leather prevents the Air's getting into the Glasses, whose edges are truly ground, and is of use for that purpose beyond any Cement whatsoever. By the use of it we can make several Experiments in the same time they formerly could make one, without any daubing or difficulty.

Another Excellency of the pump is, the *Contrivance* of the *Gage*, denoted by l, l, l, l,

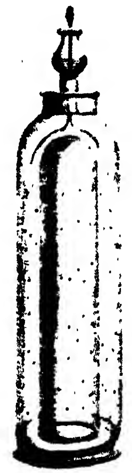
which *Gage* is a Glass Tube about 34 inches long, and is so plac'd that it cannot easily receive damage, a Circumstance to which I invite the Attention of other *Makers* of *Philosophical Instruments*. Its lower Orifice is plung'd into a Glass of Mercury, describ'd by mm, on the surface of which is laid a piece of Cork with a hole in the middle for the Glass Tube to pass thro'. On this Cork is placed a Board made of Box Wood, about an inch in breadth, and groov'd in the middle to receive the aforemention'd Glass Tube, which is loosely loop'd on to the same by two Brass Loops, that it may have the liberty of rising and falling as the Mercury ascends or descends in the Gage. The Box Board is graduated into Inches and Quarters from the surface of the Quicksilver to 28 inches high: from thence 'tis divided into Tenths of an inch. By this Gage the Degrees of Rarefication in any Experiment are at all times most nicely to be observ'd. There is likewise an Air-cock nn to let in the Air, which is a Screw on the same fore-mention'd perforated brass.

By the aid of this Pump many *Pneumatic Experiments* may be readily tried. That all may see the manner of operation I will proceed to show the Experiment of the Bladder first made by the Honourable Mr. Boyle to illustrate the Elastical Power or Spring of the Air. We take a Lamb's Bladder, well dried and very limber, and having somewhat squeezed it so as to have but little Air included in the Folds, we secure the Neck tightly with packthread. After two or three Exsuctions of the Ambient Air by means of the Pump the Bladder begins to swell by virtue of the Imprisoned Air, until it appears as plump as if it had been blown up with a Quill. Nay, if a just proportion of Air be left behind before the neck be secured, the Bladder will be broken by the Force of the Contained Air, with a Great Report, almost like a Craker. When the Air is allowed to return into the Receiver the Bladder, if it be not broken, will return to be full of Wrinkles, as before. I will likewise effect before you the tumescence of a shrivell'd Apple, which can be made to appear as smooth as one fresh gathered. A more *novel Experiment* is to write upon a Paper with a Piece of solid Phosphorus, and place it within the Pump, when the Phosphorus will brighten by Degrees, and at last throw up a lucid Cloud to the Top of the Receiver. Or again, I have here in a Bottle a mixture of divers Oils in which two or three small pieces of Phosphorus have been allowed to stand, and I turn the Bottle so that all the inward Parts are moistened by the Oil. You'll see that in the dark it yields but little Light. Nevertheless, being placed under the Receiver, upon the exhaustion of the air the whole Bottle becomes of a sudden *plainly luminous*, and so continues with increasing Rarefaction of the Air. Upon the re-admission of the Air the Light vanishes. Of *Experiments pneumatical* there is further great Variety, which I have at one time and another exhibited to the *Virtuosi*.

I now turn to the Performance of what I have promised, notably the *New Experiments* concerning the *Production* and *Emission* of *Certain Kinds of Light* from different bodies. And first I'll endeavour to *gratify* the *Ingenious* by a Trial of some new Experiments on the *Mercurial Phosphorus*. For although before now it has been observed that a shaking of the Tube of the mercurial Barometer will produce a pale Light in the Torricellian Vacuum, yet, I dare assert, nothing near what I have produced has before been seen, either for *Brightness* of the *Light*, nor for an *Elucidation* of its *Nature*. But I must prelude my Discourse on the Mercurial Lights and on the light produced by the Electricity of Glass by remarking that a *Humid Air* is very *unfavourable* to these Appearances, and will oftentimes render the Experiment unsuccessful, or at least take off very much from the Appearance of it. For the Mercurial Experiments the Quicksilver must be very fine, and free from the least appearance of Soil on its Surface, and the Glass must be made very clean and dry; nay, a prolonged Heating before a glowing Fire is to be counselled if the Weather be moist. Likewise in the new Experiments which I shall perform before you touching the *Lights produced by the Attrition of Glass*, it is necessary to have the Glass very clean and dry. The *Electrical Effluvia* which come from the rubbed Body are so subtle that the least trace of

more gross or solid Particles serves as an Impediment to their Passage. And I dare conjecture that in a moist Constitution of the Air, which is not infrequent in our *Watery Climate*, the aqueous Parts with which the Air is clogged may run together and condense on the Surface of the Glass, and so *choak up* and obstruct the passage of *the subtle Matter* which otherwise would be vigorously expelled. So that if our Experiment should fail something of the full Appearance, I beg that you'll not set us down as Bunglers, but blame something on the Atmosphere, which is less hurt by Censure.

To show you the Mercurial Phosphorus, I have here a Glass Globe, the Mouth of it being closed by a *Brass Cap*, which has a *Cock* inserted in the middle of it. The globe contains Fine Quicksilver and I have previously exhausted it of its Air by the help of a hollow *Brass Wire* which screwed both to the Cock and the Pump. When the Globe is moderately shaken, the Mercury appears luminous all round with a light of a very pale colour. If I now admit Air into the Cavity of the Globe, and once more shake the mercury, you'll see that the continued circle of light is lost. A few little *Sparkles* or *Stars* of Light do, indeed, appear, but this Light is very different from that produced *in Vacuo*, or a much Rarified Medium.

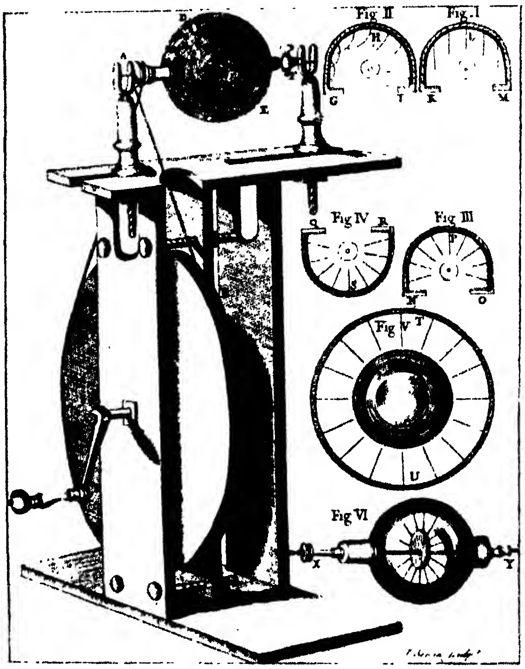


I'll show you the Mercurial Phosphorus in another way, like a *Fountain of Fire*. I have here a Receiver about 21 inches high, to the top of which I have cemented a Cupping Glass by the help of a turned Brass Piece. The Aperture of the Cup I have closed with a round little Plug of Wood, to prevent the Mercury entering the Receiver before its due time. Within the tall Receiver is a glass, which has a round Crown like a Shade (as they generally call those Fences which are put over Images to keep 'em from the Dust). The *Apparatus* being already exhausted, I loosen the Plug, and the Mercury is driven by the Pressure of the Air with great violence into the Receiver, giving the surprising appearance of a shower of Fire compassing the shade.

Another Experiment is performed by means of a Globe which I have closed by a Brass Cap, in the Middle of which is fixed a Stop-cock that has a small Glass Tube or Quill inserted into the lower Orifice of it. When the Globe is laid on its side the Mercury which it contains lies clear of the Extremity of the Tube, and the Globe can be exhausted, which has already been done. When the Cock has turned, the Air has free liberty to enter, and rushes with great violence through the Mercury, blowing it up forcibly against the Sides of the Vessel. And in the confusion and hurry of its parts the Mercury gives all round the *Appearance* of *Fire*. And I have found that this Appearance continues until the Globe is half filled again with Air. And I have shown by the Help of the *Mercurial Gage* that although the Mercurial Phosphorus is not producible in so *Dense* a *Medium* as *Common Air*, yet it by no means requires so thin and so rarefied a Medium as that which makes a near approach to a Vacuity. From what has been shown, and tried by me on other Occasions, we may infer that a peculiar Figure and Motion of the Parts, as well as a proper Medium for the Motions, are requisite for the Production of the Mercurial Phosphorus. There's no Light without Motion, and the Light is produced by the Rubbing, as it were, of the Mercury on the Glass. Yet that Glass itself is not the prime Cause I have proved by putting Mercury in a varnished Galley-pot, which being put under the Receiver and shaken in Vacuo, a Light appeared.

I'll now make Trial of some *Electrical Experiments*. I have here a Tube, or hollow Cylinder, of flint Glass, fitted with a Brass Cup and Cock, and to spare time, I have exhausted the Air from the Tube before the Discourse. I'll now rub the Tube pretty vigorously with Paper in my Hand. Now while you'll see later that if the Tube be rubbed when full of Air it manifests *Surprising Attractions*, yet now, the attractive Power is very little

discernible, for it produces no Motion, or but confined Motion, in Pieces of Leaf-Brass scattered on the Table. If the Air be now admitted by a turning of the Cock, and I rub the Tube again, (but no more vigorously than before) and hold it towards some Pieces of Leaf-Brass, no sooner are they within the *Sphere* of *Activity* of the *Effluvia* emitted by the Tube but they begin to be put in brisk Motion. They will leap towards the Tube at a very considerable Distance from it: sometimes they will adhere and fasten themselves to the Tube, and there remain quiet, and sometimes they will be thrown from it with great force. It is no small Entertainment to perform this experiment with Particles of *Lamp-Black* in place of Leaf-Brass and to observe the brisk and lively Motions produced by the Effluvia. I have observed much concerning the Attrition of Glass Cylinders, but I can discourse but little of it, for shortness of time. But I'll now show you that when the exhausted Tube is rubbed, a Light is produced *within the Tube* which is clearly discernible in this *darkened Room*, but when the Tube full of Air is rubbed a Light, it is true, will follow the Hand backwards and forwards, but seems to be altogether on the *Outside*. And I would propose by way of a Query whether the effects of the Effluvia are so much greater when the tube is full of Air than when it is exhausted because of a *Difference in the electrical Equilibrium* of the External Air and the Air included in the Cavity of the Glass Tube, which is manifested also in the *Difference of the Light*.



Hauksbee's Electrical Machine. For a contemporary description of this machine see p. 136.

The Electrical Effects of the Attrition of Glass can be made much more conspicuous by the help of my *newly devised Electric Machine* which you see before you. I have here a well-dried Glass Globe, to which has been adapted a Brass Cap with a Cock, by means of which the Air can be exhausted from the Cavity of the Globe. The exhausted Globe I now fix to a Machine, which is adapted to give it a swift Motion with its Axis parallel to the Horizon. When I apply my *naked Hand* expanded to the Surface of it, in a very little time a *considerable Light* is produced by a very slender Touch. If the Cock be now somewhat turned so that the Cavity of the globe slowly becomes more and more replenished with Air, there is a great change in the Light, for when, as far as I can guess, about half the Air is restored, the Light begins to branch about in pleasant Figures from the Side of the Globe which is touched by the Hand. But when all the Air is once more in the Globe, no Light appears within the Globe, but Specks of Light on the outside appear to adhere to the Fingers. Nay, while my Hand continues upon the Glass, if my Assistant approach his Fingers towards any part of it, a Light will be seen to stick to 'em, at a Distance of an inch or thereabouts, without their touching the Glass at all. Further, it has been observed by others that my Neckcloth, at a distance of an inch or two from the Globe, appeared of a fiery Colour. And I have used a Piece of white Sheeps-leather, with the Wooll-side next the Globe, to rub the Globe, in place of my Hand, with a like result.

The highest Degree of Rarefication is by no means necessary for the production of a Light

within the Globe. So that there is a strange *Congruity of Appearance* between these *electric Experiments* and the experiments with the *Mercurial Phosphorus*, which leads me to Conjecture an Electrical Origin for the Mercurial Light.

Another striking Appearance can be produced by taking the long Glass, whose Air has been exhausted, and holding it near by the unexhausted Globe at the same time as I give the moving Globe an Attrition with my hand. Immediately a Light is produced in the long Tube although it neither touches the moving Globe nor is provoked itself by any immediate sensible Attrition. And by repeated approaching of the Glass repeated Flashes can be produced.

I have made divers other Experiments by means of which Luminous Appearances may be provoked, and in particular I have rubbed a glass Globe by means of woollen Gartering wrapped about the Arms of a Brass Spring, the whole being enclosed in a large Vessel made vacuous. And I have turned an exhausted cylindrical Glass within a larger cylindrical Glass which I rubbed with my hand, and so provoked a Light within the exhausted Glass, which I think to be the greatest yet produced in any Experiment on this Subject. But the Elaboration of such a Machine exceeded that which my able Mechanic Robert Paul could perform in the time disposable, so that I beg you'll accept my assurance that the Appearance much exceeded what I have been able to show to-night.

To render the *luminous Effluvia* more remarkable, I have provided a Construction of Wire by means of which a circle of thin Muslin is made to surround the Globe. The Glass being put in motion, the Light throws itself abroad vigorously, and settles in small lucid Sparks at the ends of the torn Threads.

Touching the *electrical Attractions*, I have thought to render them visible by means of a Device which you see here. I have contrived a Semi-circle of Wire, which has several Pieces of Woollen Thread hanging down from it at pretty nearly equal distances. When this is placed so as to encompass the surface of the Glass and the Globe is turned while I apply my Hand to it, the Threads are all drawn so as to point harmoniously to the centre of the Globe, notwithstanding that if there be no Attrition the Threads are forced aside by the rapid Motion of the Air engender'd by the Movement of the Globe. Further, if the Circle of Wire be reversed, so as to encompass the lower part of the Cylinder, yet the Threads are still erected in straight lines pointing to the centre of the Globe. And by shifting the place of Attrition hither and thither, I can draw the Threads to this or that place.

I might detain you for a great while, had I the Boldness and you the Patience, discoursing of the *marvellous Effects* and Nature of the *electric Effluvia*. For I have tried many Experiments with Globes or Balls of other substances than Glass, of which you can read, should you condescend, in my book *Physico-Mechanical Experiments*, lately published, and to be had at my House in Wine-Office Court, in Fleet Street. But I fear to become tedious, and the Time apportioned to me is at an end. I have now brought before you many examples of the *Mercurial Phosphorus* and of a *strong Electrical Light*, and have endeavoured to show a certain *Likeness*, or, as it were, *Kinship* between the two *Phaenomena*. And as for the Light in exhausted Vessels, I think none before has obtained it, nor the true electrical Spark and crackling Noise which I have produced with my Machine. I may conjecture with the learned Dr. Wall, who lately (but after I had already shown my Experiments to the *Royal Society*) published something touching the *attractive properties* of *Amber* in the *Transactions* of our *Royal Society*, that the Light and crackling do in some way represent Thunder and Lightning.

I am myself persuaded that in the electrical Effluvia whose workings you have beheld lie the Seeds of great Matters, and that a *due Study of these strange Properties of Bodies* may do much to *establishing a True System of Nature*. And when we consider how by means of this hitherto unheeded Influence we may already produce a Light which will

permit Print to be read, may we not be allowed to conjecture that future Ages may find out a means for so increasing the *Power* of the *Electrical Agent* that by the mere *Turning* of a *Machine* a Light may be produced which will rival that of these Candles, and illuminate a whole Room? Again, may not the Considerations of the Nature and Laws of the electrical Attraction be applied to the Production and Determination even of the *Involuntary Motions* in the *Parts of Animals*, of which very little has yet been wrote intelligibly? Nay, more, when we consider how *lively* are the *Motions* which this *subtle Effluvium* may produce in light Bodies may we not by a *Prophetical Imagination* in our Thoughts be bold to believe that an Age shall come when *Chariots* may be driven by the electrical Power alone? Just

FIGURE 1. This Plate is in Reality but a compound Inſtrument or Apparatus, for trying the Electricity of Glaſs, and its Luminouſneſs, when put into Motion, and rubb'd upon to heat it. Wherein B C is a Wheel, with its String A B C. D E is a Sphere of Glaſs, whoſe Air has been drawn out by the Air-Pump: This is turned round by the former Wheel-ſtring at A. F is a Stopcock, whereby the Air is exhauſted, and may be readmitted at Diſcretion. In this Figure K L M is an Arch with Threads of Cruel or Yarn upon it, as they hang about the Glaſs D E, (here repreſented by a ſmaller Circle within the Arch,) before it is turned round or heated by rubbing.

Fig. 2. G H I is the ſame with the former; only the Threads are here repreſented as they hang at the beginning of the turning round of the Globe, before it be heated by Friction; being plainly bent one way, by a Wind ariſing from that Convolution.

Fig. 3. N P O is the ſame; only with the Threads pointing towards the Sphere, or its Center, when the Arch is in an upright Poſture, and ſome of the Threads hang partly downwards, and this upon the Spheres being heated ſufficiently.

Fig. 4. Q S R is the ſame, with its Threads pointing the ſame way, though in a downward Poſture, when ſome of the Threads thereby are forc'd to ſtand erect.

Fig. 5. T U is a Circular Arch, in an horizontal Poſition, when the Threads point towards the ſame Center, in the ſame horizontal Plain.

Fig. 6. Is another Sphere, communicating with the Air, and to be apply'd to the ſame Wheel in the Room of D E, where-into is inſerted an Axis with a Circle affixed to it; at the Edges of which Circle the Threads are placed. Theſe upon the Friction and Heat of the Glaſs extend themſelves outward, and point from the Center to the Circumference, contrary to the former. In both Caſes the Threads, when under the Influence of the Electricity, will be moved by the Finger, even without Contact, nay by the Finger and Breath, even through the Glaſs it ſelf; ſo ſubtle are theſe *Effluvia*. The Light is made when the Air is exhauſted, and diminiſhes as you readmit it. It ſpreads and branches it ſelf inwardly like Lightning, when about half that Air is readmitted. The Colour of that Light is always Purple. It ſpreads at ſome Diſtance, and makes the Edges of a Cravat look a little like the milky Way, by the great Number of Sparkles it emits: Which may alſo be felt by the Fleſh, with a crackling Noiſe that accompanies them. If you alſo ſufficiently rub and heat a large Tube of Glaſs, either ſolid or hollow, it becomes ſtrongly Electrical, even through Glaſs it ſelf, tho' not ſo much through Muſlin. Other Heat than that by Friction ſignifies nothing. It will attract and repel Leaf Gold, and the like ſmall and light Bodies, after a ſtrange manner, by turns; when once they have been fully repell'd they cannot be made to touch them, till they have been reflected from ſome other Body. If they lye between two Pieces of Wood, laid pretty near, the Electricity fails of its Effect. With other Circumſtances very ſurprizing and unaccountable.

Contemporary description of Hauksbee's Electrical Machine (see figure on p. 134)

as a man who had seen Straws and tenuous Fragments moved by a languid Motion of the Air, but had never known a Full Wind, might speculate that such an Invention as our Wind-mills, which perform the tasks of many men by *Aerial Agency*, should be possible.

If the few hints and suggestions in this discourse should excite the *Curiosity* of *ingenious Enquirers* to make further Search into these Matters, my Intention in coming before you this Evening will be completely answered.

Notes on the Construction of Hauksbee's Pump (*ante* 1709) *used in the lecture, prepared by* ROBT. W. PAUL.

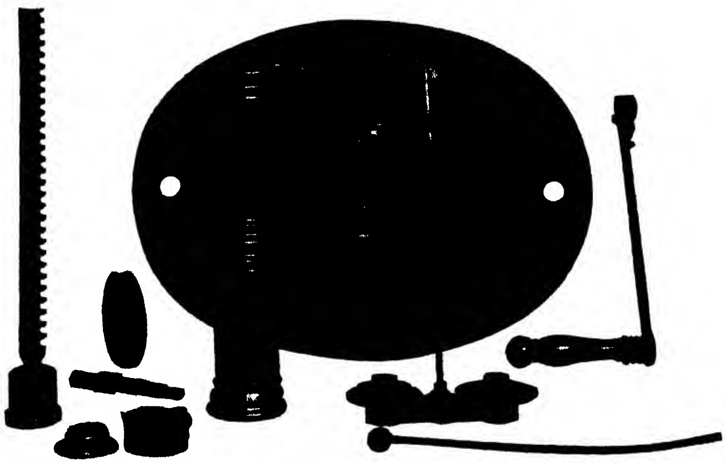
THE following details may be of interest, in view of the fact that, at the date of construction, the screw-cutting lathe, the revolving boring-bar and the cupped leather for pistons had not been invented. The principal elements of the pump are shown on p. 137.

The barrels are $12\frac{1}{2}$ inches long and the boring seems to have been done in a lathe; in each the diameter of the bore varies between 2·030 and 2·040 inches, and the tool marks

are still visible in a considerable part of the length of the barrel. The lower end of each barrel is chased out with a V-thread, 18 to the inch; the diameters differ by only ·005 inch, and the barrels can be interchanged on the male threads. The suckers are similarly screwed, but 18 threads per inch.

The sucker leathers consist of three thicknesses of thin leather, puckered at their upper ends.

The racks consist each of two thicknesses of sheet brass, brazed together to make up the requisite thickness; the teeth are marked off with centre dots as a guide for filing them. The pinion is a thick brass disk on which the teeth are formed, and two thin disks are riveted on to form shrouding and to give a bearing surface against the wooden "frontispiece," which has brass bushes for the iron spindle; the latter is squared into the pinion, and into the crank forging. The spindle has a thread for the nut, and the thread (13 per inch, ·390 diameter) has apparently been formed by squeezing into a solid die.



Components of Hauksbee's Pump

The figure shows a union on the pipe; the joint is made by a leather washer, compressed by a screw tapped into a yoke, the latter being riveted on to the perforated brass block secured to the receiver plate. The gauge tube attachment is similar.

The stand is beautifully made in walnut; the two pillars holding the "frontispiece" have threads cut on them, 1 inch diameter, ¼ inch pitch; the ornamental nuts on these hold the barrels to the base.

Wood-screws are used for fixing the "swan-necked" stays to the base; these screws are forged, and their threads filed out with a round file; a wrapped wire or string was probably used as a guide for filing.

The pump is the treasured property of the Royal Society, to which thanks are due for the opportunity of examination. As received, the receiver and the gauge, with its attachments, were deficient; on reconstructing them and putting in new leathers the pump worked properly and gave a vacuum within about one inch of perfect vacuum.

THIRD LECTURE. JANUARY 6TH

TELEVISION. By J. L. BAIRD

I SHOULD like to begin this talk with a definition of the word "television." It may be defined briefly as the transmission by telegraphy of the images of actual scenes with such rapidity that they appear instantaneously to the eye.

The eye, fortunately for the success of television, has a time lag, and the images therefore need not actually be transmitted instantaneously; in fact, if they are transmitted at the rate of 16 per second, the transmission appears to the eye to be instantaneous.

In television then we have to transmit 16 images per second; these images it should be clearly stated are not photographs, but images of the actual living scene.

The transmission of 16 photographs per second would not give television, but would be the transmission of a cinematograph film or telekinematography.

The problem of television has been approached by two different methods. The first and most obvious was to build an apparatus in imitation of the human optical system. The human eye consists essentially of a lens which casts an image of the object viewed upon the retina.

The surface of the retina consists of several millions of hexagonal cells into which come nerve endings from the optic nerve; these nerve endings are immersed in a light-sensitive substance, the visual purple; this substance is ionized by light, changing its colour from rose-red to orange.

The ionization of the visual purple sends impulses along the nerve fibres to the visual centres of the brain.

The visual purple in life is continually regenerated so that in effect the eye might be compared to a cinematograph camera, with the difference that in place of using a moving film coated with a light-sensitive emulsion, the light-sensitive emulsion itself is continually resensitized.

In the human television system the scene viewed is transmitted to the brain as mosaics consisting of an enormous number of little areas, each of these little areas being transmitted at the same time to the receiving centres of the brain; here they produce mosaics of electrical impulses corresponding to the image on the retina.

Artificial television models on these lines were actually made by several early workers. Rignoux and Fourner in 1906 constructed an apparatus, the transmitter of which consisted of a wall covered with 64 large selenium cells, each of these cells being connected to a corresponding shutter at the receiving station, so that when light fell on any cell its corresponding shutter opened at the receiving station and a spot of light appeared on the receiving screen.

By covering the transmitting wall with large stencils, shadowgraphs of letters and geometrical figures were transmitted. The stupendous number of cells, wires and shutters required made the development of such a scheme out of the question.

The second line of attack was to use one cell only and cause each of the elemental areas to fall in succession upon this one cell, the carrying current from the cell to be transmitted to the receiver and there control the intensity of a point of light traversing a screen in synchronism with the traversal of the image over the cell; this point of light to be bright at the high lights and dim at the shadows and make eight complete traversals of the screen per second, so that persistence of vision would cause the whole image to appear instantaneously to the eye.

To devise optical apparatus capable of causing an image to traverse a cell proved a comparatively simple matter, and a number of such devices were already invented over 20 years ago. Fig 1 shows one of the best known of these devices, that due to Jan Van Szczepanik; this gives a good idea of a simple exploring method.

At his transmitting station he employed two mirrors vibrating at right angles to each other, the image being projected by a lens first on to one mirror, and from this mirror on to the second one, which in turn reflected it to a selenium cell. The result of the combined motions of the mirrors was to cause the image to travel over the cell in a zigzag path, and the current from the cell was transmitted to the receiving station, where it controlled the intensity of a spot of light, this spot of light being reflected in a zigzag path across a screen by means of two mirrors vibrating at right angles in the same way as the mirrors at the transmitter.

Had this been the only problem, television would have been achieved 30 or even 40 years ago.

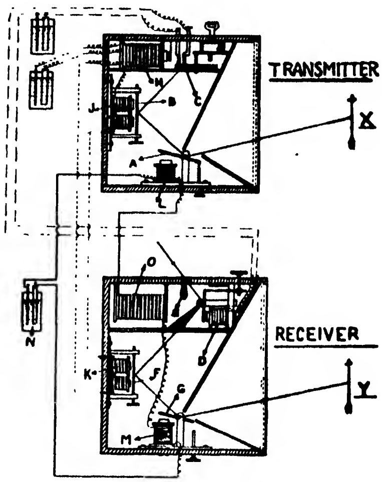


Fig. 1. Szczepanik's Television Apparatus

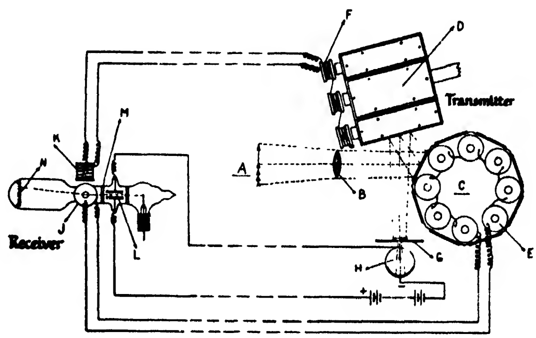


Fig. 2. Rosing's Television Apparatus

The real problem was to obtain a light-sensitive device capable of giving an adequate response at the immense speed of signalling necessary. Two light-sensitive devices were available to the early workers, the selenium cell and the photo-electric cell. The selenium cell proved too slow in its response, and the photo-electric cell, while instantaneous in action, gave an insufficient output.

Fleming's invention of the thermionic valve, with its subsequent development, the three-electrode valve, altered the whole aspect of the problem by giving a means of amplifying the most minute currents to almost any extent, and an attempt was made to use the valve in conjunction with the photo-electric cell.

Again, however, disappointment was in store. Even the stupendous amplification now obtained was insufficient, with a potassium cell, to obtain an adequate response. This would require, I estimate, an amplification at least a thousand times greater than that obtainable with the present thermionic valve.

At very large amplifications the intrusion of parasitic noises due to battery irregularities and other causes sets a practical limit to the amplification obtainable. By great care this limit can be extended, but even then a further limit arises in which the noise due to irregular emission of the valve filament makes its appearance. The valve, however, in conjunction

with the potassium photo-electric cell, while it did not produce television, enabled shadows to be transmitted, for with shadows the light problem does not arise, the cell having only to distinguish between complete darkness and a light which may be almost as intense as we like to make it.

In television, however, only the light reflected back from the elemental areas of the image is available, and this light is infinitesimally small. The first problem, then, was to produce a device capable of giving an adequate reaction to this infinitesimally small stimulus.

Before going further I would like to show a few slides illustrating the work which is being done abroad, and also to mention two original systems suggesting the use of the cathode ray. Fig. 2 shows the device suggested by Rosing. His transmitting arrangement consists of two mirror polyhedrons revolving at right angles, their combined action causing the image to traverse a photo-electric cell. For his receiver he employed a cathode ray traversing a fluorescent screen. By this means he abolished mechanical inertia at his receiver but not at his transmitter. Mr Campbell Swinton published a letter in *Nature* prior to the publication of Rosing's scheme and in this letter he suggested a scheme using the cathode ray

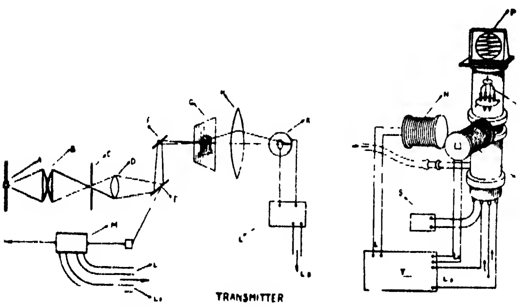


Fig. 3. MM. Belin and Holweck's Television Apparatus

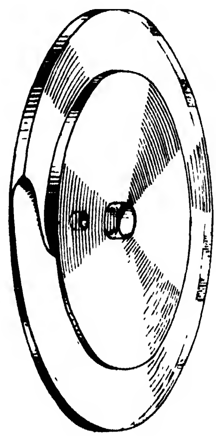


Fig. 4. Jenkins Prismatic Disk

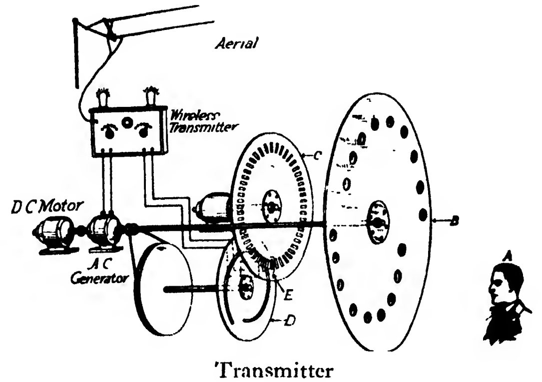
both at transmitter and receiver. His transmitter consisted of a mosaic of potassium cubes traversed by a cathode ray; an image of the object to be transmitted was projected on the mosaic at the receiver; the scene was to be reproduced by a cathode ray traversing a fluorescent screen.

Dr E. E. Fournier D'Albe, the inventor of the optophone, has made the very original suggestion of using light interrupted at different frequencies, one frequency corresponding to each element of the image, transmitting the image as a medley of notes and separating the medley into its original constituents at the receiver, by means of tuned resonators, each resonator corresponding only to its own note.

Fig. 3 shows the apparatus of MM. Belin and Holweck. They are reported to have succeeded recently in sending shadows with this apparatus. The transmitter of Belin and Holweck consists of two mirrors vibrating at right angles to each other, and these mirrors cause the image to traverse a potassium photo-electric cell. The current from this cell controls the intensity of a cathode ray at the receiver, the ray being caused to traverse a fluorescent screen by magnets which are energized from an alternating current transmitted from a motor which moves the mirrors at the transmitter.

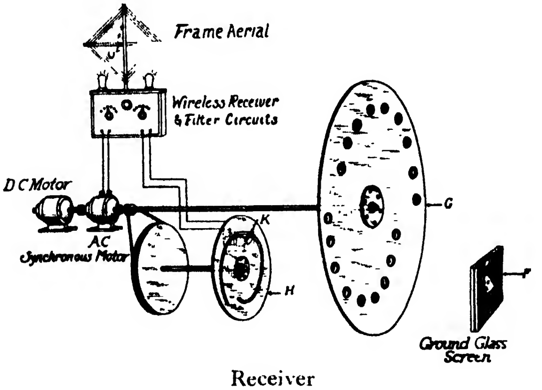
Fig. 4 shows the prismatic disk used by Messrs Jenkins and Moore. In the U.S.A. Mr Jenkins, whose name, like that of Monsieur Belin, is known in connexion with photo-

telegraphy, has, in conjunction with Mr Moore, also succeeded in transmitting shadows. To cause their image to traverse the cell they use a prismatic disk. This consists of a circular glass disk, the edge of which is ground into a prismatic section, the section varying continuously round the circumference. Light passing through the disk is therefore bent backwards and forwards as the section changes, and by passing the image through revolving disks of this nature, it is made to traverse a photo-electric cell. The current from this cell is transmitted to the receiving station, where it controls the light from a lamp invented by Mr Moore. This lamp changes its intensity instantaneously in proportion to the current, and its varying light is caused to traverse a screen by a similar device to that at the transmitter.



Transmitter

Fig. 5. *A*—The object to be transmitted. *B*—A revolving disk with lenses. *C*—A slotted disk revolving at high speed. *D*—A rotating spiral slot. *E*—The aperture through which the light passes to the light-sensitive cell



Receiver

Fig. 6. *F*—Reproduced image. *G*—Revolving disk with lenses. *H*—Rotating spiral slot. *K*—The aperture through which the light passes from the varying light source

About four years ago I decided to devote my entire time to an effort to achieve television. The problem seemed comparatively simple. Two optical exploring devices rotating in synchronism, a light-sensitive cell and a controlled varying light source capable of rapid variation were all that were required, and these appeared to be, to use a patent office term, already "known to the art."

The problem of synchronism had been seemingly already practically solved in multiplex telegraphy and quite a number of optical exploring devices were already known. The photo-electric cell in conjunction with the thermionic valve appeared to offer a ready made light-sensitive device, and the glow discharge lamp an ideal light source.

The only ominous cloud upon the horizon was the fact that in spite of the apparent simplicity of the task no one had produced television.

The trouble lay in the cell; after some six months work I managed however to get shadows through. The step from shadows to images by reflected light proved extremely difficult, but in April 1925 I had the satisfaction of transmitting simple outlines by reflected light. Fig. 5 gives a diagrammatic representation of the optical method used. By means of a disk *B* containing 6 lenses in staggered formation, a series of strips of the image were caused to traverse *E*, the aperture of the light-sensitive cell, after being interrupted by the slotted disk *F*. The spiral disk *G* gave a finer grain to the image by subdividing the strips. At the receiving station a similar optical apparatus was employed, and Fig. 6 will show the arrangement. The light-sensitive cell was replaced by a glow discharge lamp *K*, the light from which was controlled by the current from the light-sensitive cell. The two mechanisms revolved in synchronism and thus a light spot of varying intensity was caused to traverse the screen *F* and give a reproduction of the image.

Synchronism was obtained by coupling a small A.C. generator to the shaft of the transmitting apparatus; current from this generator was transmitted to the receiver and after amplification controlled the speed of a synchronous motor.

An apparent weak point of this device in common with other mechanical systems is the difficulty of obtaining a sufficiently fine subdivision of the image. The difficulty of making a slotted interrupter capable of interrupting the light at high frequencies I overcame by making the interrupting disk in the form of a circular grating with fine radial lines and rotating it in front of a grid of the same pitch.

The further difficulty of the limit set by the speed at which it is possible to revolve such disks was first met by using two cells and sending in two adjacent zones.

We are however now developing along different lines and have not so far found it necessary to use more than one cell.

The outlines transmitted with this first machine were crude and flickering and simply outlines, no gradations of shading and no detail being visible.

The next step—to produce a real image with light gradations and detail—was a good deal more difficult than I anticipated. The image persisted in coming through simply as a black and white effect; after some six months, however, the remaining difficulties were overcome and I had the very great satisfaction of seeing at last on the receiving screen a real image with gradations of shading and detail.

An interesting phenomenon in connexion with television is that if the television transmissions are received on a telephone receiver they are heard as sounds, every object or scene having a corresponding sound.

In televising a scene, it is first transformed into a fluctuating electric current, the current variations depending upon the scene in front of the transmitting televisor; these fluctuating currents are sent through the ether in the form of a modulated carrier wave just as in the transmission of telephony the noise is carried, only in this case the modulations correspond to a scene instead of a sound.

The vision modulations are also audible if received on an ordinary wireless receiver and are heard as characteristic sounds, each scene having its corresponding sound.

Different faces make different noises and it is possible to distinguish one face from another by its sound.

I have taken a few phonograph records so that you will be able to hear these image sounds.

The first record gives the sounds made by the faces of three different people and by listening carefully it is quite possible to hear the different characteristic notes.

These sounds you have just heard are the sounds made by the faces of three members of the Physical Society who were kind enough to submit themselves to the experiment.

The second record gives the image sounds of a pair of scissors, a match box, a bowler hat and a cabbage.

These sounds form permanent records of the scenes they correspond to. They may be reconverted into electricity by playing the phonograph in front of a microphone, and by using this electrical output to actuate a televisor synchronized with the phonograph the original image may be reproduced.

This gives a possible method of storing living images as phonograph records.

In the first demonstrations of television it was necessary to use an intensely brilliant illumination and this caused considerable discomfort to the persons being televised.

During the latter part of last year I spent considerable time in overcoming the necessity for this very brilliant lighting and ultimately managed to get it down to a normal value; and while engaged on this work the idea occurred, why not dispense with light altogether and use rays outside the visible spectrum? The first attempts were made with ultra-violet rays. These rays have a powerful photo-electric effect but unfortunately they have also a very low penetrative power, being unable to penetrate glass and being rapidly absorbed by the atmosphere. In addition they have the further serious practical disadvantage of having a very bad effect on the eyes of the sitters.

These difficulties led to an endeavour being made to use the invisible rays at the lower end of the spectrum, that is to say, the infra-red rays.

These rays have very great penetrative power and have no unpleasant effects upon the human body. Unfortunately they have only a small photo-electric effect.

The use of these rays in place of light ultimately proved successful and enabled all lighting to be completely dispensed with; giving the somewhat remarkable result that it was possible to see a person sitting in total darkness.

In television this does not offer any obvious advantage as there is no reason why the scene should not be illuminated in the ordinary way, and it is much easier to transmit a normally illuminated scene than it is to transmit a scene in darkness.

The fact that the infra-red rays are invisible should however make their application to the televisor useful in military and naval operations.

The fact also that these rays to a great extent penetrate fog may possibly open up a use for a development of the infra-red televisor in the mercantile marine.

DESCRIPTIONS OF THE EXHIBITS

SCIENTIFIC ELECTRICAL INSTRUMENTS

H. TINSLEY & CO.

Messrs H. Tinsley and Co. showed the latest model of Professor MacGregor-Morris's hot wire anemometer in a portable form, suitable for measuring air currents in coal mines and the ventilation of buildings, from a few feet to about 200 feet per minute. Improvements enable the air temperature to be measured electrically and the proper corrections for it to be applied. A further simple arrangement enables the proper standardizing current to be established in the apparatus. The instrument is an interesting example of the increasing exactitude of technical requirements, stimulating the provision of the necessary refinements without undesirable complications.

Another instrument was a sensitive ten-coil reflecting dynamometer specially designed for measurements at nearly zero power factor, four current ranges being available by the

usual multiple switching arrangement. It promises to be valuable for investigating the energy loss in dielectrics, and is stated to be sensitive to 0·0001 radian of phase difference.

An instrument designed for alternating currents was a frequency bridge due to Dr Pedersen of Copenhagen, having the advantage of being suitable for low and high frequenceis. By means of three different values of a mutual inductance three ranges of frequency—zero to 1000 cycles, zero to 2000 cycles and zero to 5000 cycles—are obtainable, the frequency being obtained in terms of the square root of an adjustable resistance.

A four-phase tuning fork has been designed to produce a continuous torque on a phonic motor. By a special type of contact the current impulses are displaced 90° in time phase. The fork is of the double type, two long bars being clamped together in the middle. A variety of time-phase intervals can be obtained by using a number of suitably adjusted contacts.

A submarine cable duplex balancing adjustor has been devised by Mr D. C. Gall for the purpose of measuring the errors in balance. The dials indicate the resistance and the reactance errors. Measurements are made at a variety of frequencies, from which the position at which adjustment is required in the artificial cable is determined on a chart.

Among the apparatus for direct current measurements was a low resistance for a large current, made of manganin rods in parallel, similar to designs in use at the National Physical Laboratory. This form is stated to be more satisfactory metallurgically than sheet material. Resistances for measuring up to 10,000 amperes are under construction.

The "Hoopes" Bridge is a modification of the Kelvin Double Bridge for the purpose of determining rapidly the relative resistance of samples of copper wire to a good commercial accuracy. A definite length is cut off by a machine, weighed against a special "nominal" weight and the difference noted. The specimen is put in the bridge, the above "weight" correction is applied mechanically, and the electrical balance gives the percentage conductivity, a copper reference standard being used to avoid temperature corrections. An accuracy of 0·1 per cent. is claimed.

A curve tracing machine of the ondograph pattern gives an ink record of a repeating periodic function. It was shown recording the behaviour of a phonic motor.

Messrs Tinsley also showed a large selection of their fine instruments such as the coordinate potentiometer, and low reactance resistances.

M-L MAGNETO SYNDICATE LTD.

Two interesting methods of measuring peak voltages by portable instruments were shown by the M-L Magneto Syndicate Ltd. In one type, for voltages up to 300, the voltage is rectified by a diode valve, and charges up a condenser in the usual manner. The common method of measuring this voltage, by an electrostatic voltmeter, is not suitable for a portable instrument, and the voltage, if of a suitable value, is applied to the grid of a triode valve. The valve is first set to pass a definite fairly large anode current with a definite filament voltage, the grid being connected to the filament. The rectified unknown voltage is applied to filament and grid so that the latter is charged negatively. The anode current falls to a definite value from which the grid voltage can be obtained by calibration. If the rectified voltage is too high to be suitable, the charge on the condenser is shared with one or more other condensers before applying it to the grid, the resulting voltage being arranged so as to be of a value suitable for giving a satisfactory change of anode current.

The second method, for voltages from 200 up to 15,000, has been used for measuring the voltage of sparking plugs and magnetos. After rectification by a diode valve, the voltage charges up a small condenser. This is connected to a sphere air gap, the separation of the

spheres of 20 mm. diameter being operated by a cam. The gap is varied until a spark, visible through a small hole in the case of the instrument, occurs occasionally. The shape of the cam is so formed that an evenly divided scale on its axle shows the voltage corresponding to the accepted values for different gaps.

High P.D. Peak Voltage Indicator

BAIRD & TATLOCK (LONDON), LTD.

Electrometric Titration Apparatus. An outfit for electrometric analysis of a commercial character, arranged by J. F. Spencer, consists of an accumulator, potential dividing slider resistance, portable voltmeter and galvanometer and reversing and tapping key. An electric stirring arrangement is provided for the titration vessel, and an electrolytic hydrogen generator.

Metro Gas Circulator. This apparatus, devised by A. R. Pearson and J. S. G. Thomas, consists of a hot air engine in which mercury in a U-tube is used as the piston. It oscillates automatically by the application of heat, and in doing so its motion in the part of the tube not subjected to heat is utilised as a suction and compression pump, which can be used for circulating gases or for other similar purposes.

NEW OSCILLOSCOPE CO., LTD.

Oscilloscope. One of the latest forms of Elverson Oscilloscope, depending upon periodic flashes of a Neon lamp, and so arranged that the gear box can be held in one hand and the lamp in the other, for convenience of inspection of different parts of moving apparatus.

CAMBRIDGE INSTRUMENT CO., LTD.

Two interesting methods of continuous gas analysis by electro-thermal methods have been developed. One of these is for the measurement of oxygen in the feed water of boilers. The oxygen is "scrubbed" out of the water by a continuous flow of electrolytic hydrogen.

The water is passed through the apparatus at the rate of 500 c.c. per minute, and the electrolytic current being fixed at 1·4 amperes, a definite ratio of flow is established between the water and the hydrogen. The pure hydrogen surrounds one of the platinum coils of a katharometer, while the other coil is surrounded by the gas after being contaminated in the scrubber. The contaminated gas being a less efficient cooling medium, the platinum coil is more heated by the electric measuring current than the one in pure hydrogen, and the usual Wheatstone Bridge arrangement is made to indicate the quantity of oxygen up to 1 c.c. per litre of water.

The second scheme is the application of the largely used katharometer CO_2 indicator to the operation of large electro-mechanically operated dials. The dials are marked in numerals up to 18, which represents 18 per cent. of CO_2. A clockwork mechanism acts on the moving part of the galvanometer, depressing it at regular intervals on to one of two contacts, which energize the pawl mechanism of the dials and cause the pointer to rotate. This rotation alters a contact arm on a circular rheostat and rebalances the circuit. Arrangements for illuminating the pointer and dial are provided, and furthermore, by red and green translucent screens, an indication is given as to whether the proportion of CO_2 is decreasing or increasing.

Moving Iron Vibration Galvanometer. A model of the vibration galvanometer of the type described by Schering and Schmidt, for frequencies from 20 cycles to 120 cycles, has a useful field of work. It is tuned by varying a polarizing direct current of about 0·1 ampere, which is supplied by two or three accumulators. The resistance may be operated by an insulating handle so that the galvanometer can be used on high voltage circuits. The capacity is given as 8 micro-microfarads. It is shielded from stray fields and the damping is adjustable. The sensitivity per microampere at 50 cycles is about 35 millimetres at 1 metre for an instrument of 250 ohms.

Campbell Capacitance Bridge. This bridge, which has recently been described by Mr A. Campbell before the Physical Society, has been designed for the measurement of condensers from about 1 micro-microfarad to 30 microfarads, covering the whole range commonly required in commercial work. The continuously variable part is a mutual inductance, which has been designed to have a scale which can be read to about the same percentage accuracy over a large part of it, somewhat similar in proportion to that of a slide rule. The instrument also measures the power factor. A telephone is used as a detector, and the accuracy is designed to be within about three parts in a thousand over most of the range of the instrument.

Magnetic Bridge Permeameter. This instrument has been developed from the designs of Dr E. Hughes (*Proc. Phys. Soc.* **37**, 233, 1925) for the determination of the magnetic properties of iron and steel in bar form. By means of special coils the necessity of providing perfect magnetic joints is avoided, and round or rectangular sections can be used without machining. A length of bar of 4½ inches and up to ¾ inch diameter is used. The requisite magnetic condition in the measuring field is determined by a "feeler" of "mumetal." Magnetizing forces up to 1000 C.G.S. units are available, and a special system of rheostats in the magnetizing circuit enables hysteresis measurements to be carried out in a convenient manner. The dimensions of the magnetizing coil are chosen so that 1 ampere is equivalent to 100 gauss.

Surface Pyrometer. A novel type of surface contact pyrometer for curved surfaces consists of a substantial strip, half of copper and half of constantan, stretched between spring supports. The mounting contains the moving coil thermo-electric temperature indicator. The strip can be placed against any fixed or moving smooth surface the temperature of which is desired. It is claimed that temperatures up to 200° C. can be determined in 5 seconds.

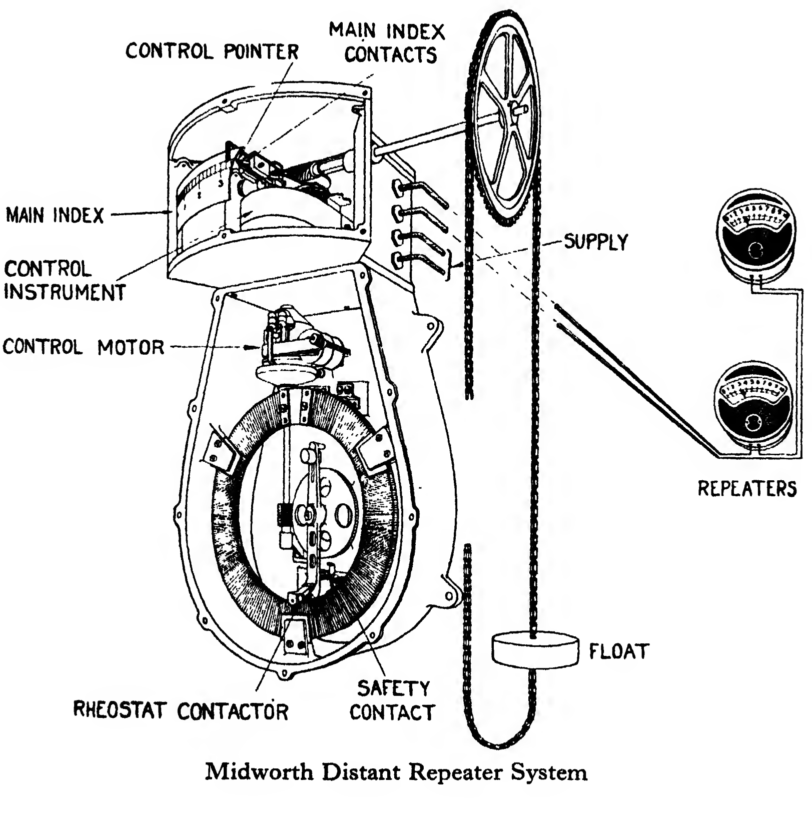
Moullin Voltmeter. This has been extended in range and is now available with a range of 4, 40 and 120 volts. A unipivot instrument having a scale 170 mm. long is used as the indicator. The effective resistance is always greater than a megohm, and the instrument is independent of frequency.

Glass Electrode Potentiometer. This instrument, using a thin membrane of glass as a separating medium for hydrogen-ion determination, which has been developed by Mrs Kerridge, has been described in the *Journal*, Sept. 1926, p. 440. By this means quantities as small as 0·5 c.c. can be used and are protected from the air while in the apparatus.

EVERSHED & VIGNOLES, LTD.

An interesting instrument, which appears to facilitate an important type of measurement, is one on the ohmmeter principle for measuring the resistance of earth plates for lightning conductors and simple purposes. By means of the use of two additional temporary earth connexions, the value of whose resistance is unimportant, an accurate measurement of the earth resistance is obtained. An A.C. hand generator is used, and by means of a rectifying commutator the currents are made suitable for ratio measurement by the usual crossed coil system moving in a magnetic field produced by a strong permanent magnet. The independence of the value of the resistance of the two temporary earth connexions was shown by a practical demonstration.

The Dionic Water Tester has been improved in detail. The glass components have now been standardized, ensuring interchangeability. Temperature corrections can be made by setting a slider to a scale before taking a measurement. When polarization is important an A.C. generator is used, the currents being rectified before being put through the D.C. ohmmeter.

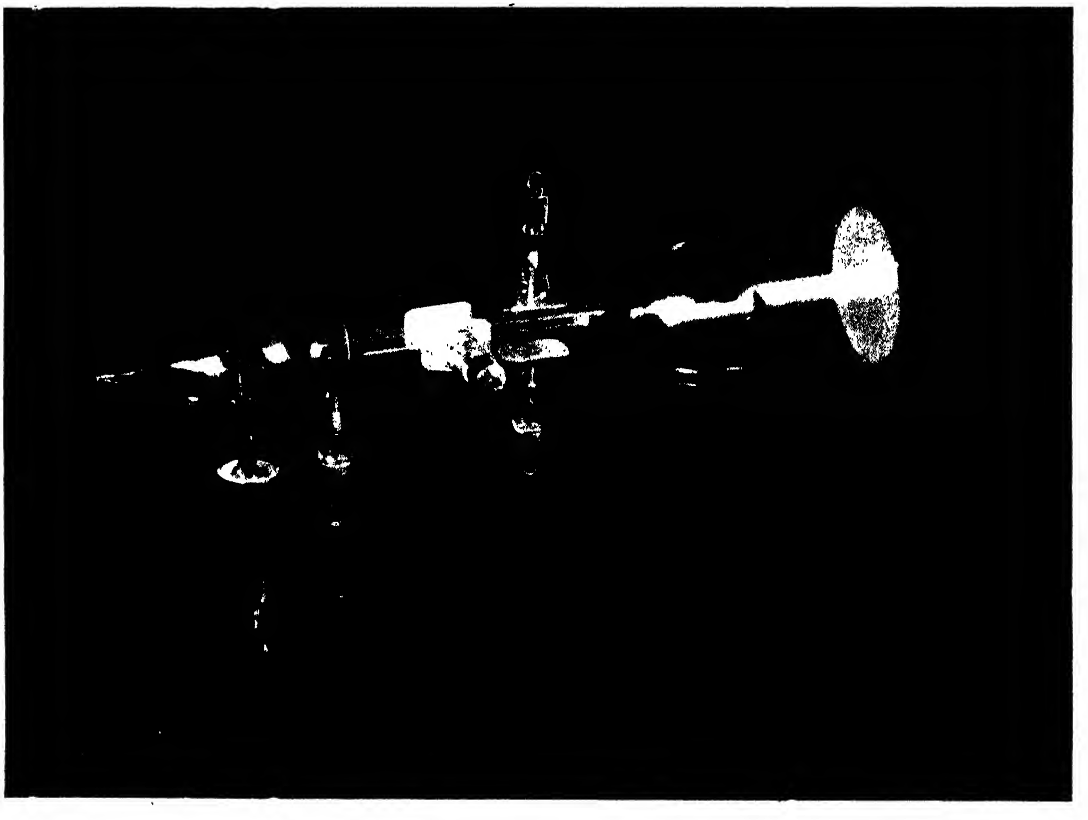


Midworth Distant Repeater System

An interesting electro-mechanical device is the Midworth Distant Repeater. By this instrument the position of a moving part of a mechanism or indicator can be reproduced electrically on one or more instruments of the nature of an ammeter. The transmitter operates on the "hunting contact" principle, by which a small motor is caused to vary the resistance in an electric circuit until the contact "floats." The scheme of operation makes the indication independent of voltage variations and of the resistance in the circuit, so that several indicators can be put in series without any modification of the circuit.

H. W. SULLIVAN, LTD.

A fine selection of instruments for accurate measurements of importance over the range of high radio frequencies down to telephonic frequencies was shown, including the multivibrator developed by Mr D. W. Dye at the National Physical Laboratory, by which high radio frequencies are obtained as direct harmonics of a tuning fork maintained in motion by a thermionic valve. A further refinement which was exhibited by Mr Dye was the direct governing of such a fork by impulses from a standard clock. Dr Wood, of the Admiralty, also gave a demonstration of a scheme for governing a tuning fork by a clock. The clock impulse is caused to govern the amplitude of the fork, and since the fork goes slightly slower if the amplitude increases, it is possible to govern its rate by increasing or diminishing the intensity of the driving impulse. Other apparatus shown by Messrs Sullivan were a range of high precision heterodyne wave meters, and various bridges and other apparatus designed for frequencies up to nearly a million per second.



Inexpensive Cathode Ray Oscillograph

W. EDWARDS & CO.

A simple and inexpensive Cathode Ray Oscillograph, with two pairs of deflecting plates, was shown. The filament is oxide coated and requires a 4-volt supply. The accelerating voltage is 100 to 200 volts. The firm also supply photo-electric cells, gas-filled or vacuous, containing potassium, caesium and potassium, or rubidium with glass, uviol or quartz containers.

P. J. KIPP & ZONEN, DELFT

The refinements and improvements in sensitivity which have been developed by Dr Moll and other workers in Holland have been one of the very material contributions to the possibilities of mensuration during the last few years. One of the simplest and most powerful methods has been the development of the thermal relay for detecting very small deflections of galvanometers and other apparatus.

Instead of using the eye as the agent for determining the balance of a Wheatstone bridge, for instance, a spot of light is caused to fall on the central manganin element of a thermopile, the adjacent metallic parts being constantan. A very small movement of the spot of light will heat one of the junctions and cool the other, so that a second galvanometer connected to the thermopile may be made to deflect much more than the primary one, an increase of a thousandfold being obtainable. The thermojunction metals are about 0·001 mm. thick, and are mounted *in vacuo* in a double walled metal tube fitted with micrometric adjustments.

E. H. RAYNER

APPARATUS AND INSTRUMENTS FOR THE RADIO WORKER

A NUMBER of instruments and pieces of apparatus of interest to the worker in Radio and High Frequency were to be seen, and although no striking novelties were noticed, there were several comparatively new things which are worthy of special note.

Apparatus for the supply of High Tension and Low Tension current from public mains and suitable for operating Broadcast Receivers or valve oscillators in the laboratory were to be seen on the stands of Igranic Electric Co. Ltd., Marconiphone Co. Ltd., and Gambrell Bros. Ltd., the latter firm fitting the unit as an integral part of a complete receiver. Elimination of all "ripple" or "hum" is claimed for these units.

The usual comprehensive range of rheostats and fixed resistances was to be seen on the Zenith Electric Co's. stand, together with A.C. Transformers suitable for high tension rectifiers and various other purposes.

Valves in great variety were shown by Mullard Radio Valve Co. Ltd., and by M.O. Valve Co. Ltd. The former had in operation a pair of DO/40 valves oscillating at 2·5 metres wave-length, corresponding to a frequency of $1{\cdot}2 \times 10^8$ cycles per sec., and the latter were showing a valve oscillating at about 1 per sec. with D.C. meters to read anode feed, oscillatory currents and grid volts. This enabled one readily to see the phasing of these quantities.

Also on this stand were noticed two novelties which are somewhat overdue in this country. The first of these is a triode valve, Type KL 1, having an independently heated cathode, Fig. 1, thus allowing it to be run from a transformer connected to A.C. mains of any frequency. The heater and cathode are not in electrical contact, and the fact that the latter is an equipotential surface results in a sharper bend at the bottom of the grid volts—anode current characteristic curve—thus making it specially suitable for anode bend rectification.

The other novelty is a full wave gas discharge rectifier, Type GR 1. This has no filament, and appears to work upon the "short path" principle. It is suitable for building into high tension battery eliminators and has an output of 50 m/a.

The principle of the "short path" rectifier is illustrated in Fig. 2. When the electrode marked "cathode" is made positive, the mean free path is insufficient to cause ionization, therefore no appreciable conduction takes place.

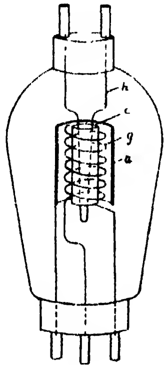


Fig. 1. Three-Electrode Valve with separately heated Cathode

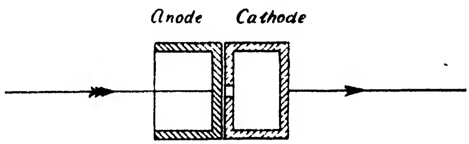


Fig. 2

When the anode is made positive the mean free path is much greater since it includes the space inside the hollow cathode, and ionization takes place with conduction as a result. The tube may contain helium at a reduced pressure.

A new power valve in the two-volt class, Type DEP 215, was also noticed. This has a large mutual conductance, over $10^3 \mu$ mho., the filament current being ·15 amp., and should therefore appeal to those who want a really large valve in this class.

Messrs Mullard were showing their P.M. series of valves, one being arranged to show the total emission, which was 45 m/a for the P.M. 5 under test. Another was exhibited with a clear patch of glass so that the filament temperature could be seen. With the rated 5·5 volts across the filament it was barely red hot. They also had a super-power valve in the four- and six-volt classes, designated P.M. 254, and P.M. 256 respectively. These have an exceptionally high mutual conductance of the order of $1{\cdot}5 \times 10^3 \mu$ mho., and are thus capable of dealing with a very large volume without distortion. A very attractive feature of these P.M. valves is their complete freedom from microphonic noises.

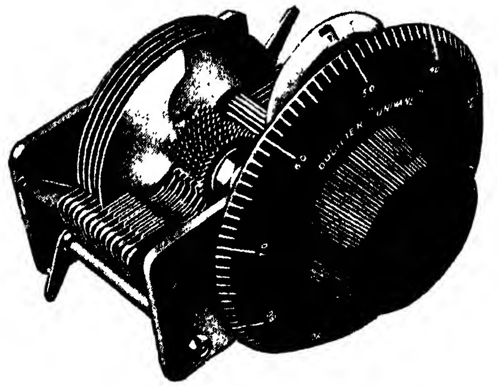
Wavemeters were shown by H. W. Sullivan, Ltd., of the heterodyne type, and in several grades. One was experimented with to ascertain to what extent the calibration was affected by a change in the H.T. and L.T. It was found that a 20 per cent. change in L.T. had no effect whatever, while a 12 per cent. change of H.T. produced a barely perceptible change in the beat note. Several of these wavemeters were fitted with precision condensers having quartz insulation, and should have a considerable field of application in High Frequency laboratories.

Messrs Gambrell were also showing wavemeters of the buzzer type at an attractive price.

A very large selection of D.C. and A.C. measuring instruments was to be found on the stands of Weston Electric Instrument Co. Ltd., Everett Edgecumbe and Co. Ltd., and Record Electrical Co. Ltd. A new A.C. voltmeter with four ranges was being shown by Weston. This is similar to their Model 280, and has an iron core movement of the Sumpner type. It should fill a long-felt want.

Radio frequency thermal instruments in several sizes and many ranges were shown by Weston and Everett Edgecumbe, the latter firm also showing a useful small size electrostatic voltmeter three inches in diameter.

Dubilier Condenser Co. (1925) Ltd. had a good display of condensers of all sorts, both fixed and variable. In the latter class the "Univane" is a distinct novelty, each revolution of the dial taking one vane in, a very long scale resulting. Low frequency transformers were to be seen on the stands of the Marconiphone and Igranic Electric Cos., the former showing four different ratios and in addition a choke of 100 henrys.



The Dubilier "Univane" Condenser

Control of valve oscillators by means of quartz crystals was being demonstrated by Messrs Adam Hilger Ltd., the plates of quartz being supplied ground to a specified wave-length. Insulating materials in the form of "Bakelite" and "Paxolin" were exhibited by the Damard Lacquer Co. Ltd.

S. WARD.

TELEGRAPHIC APPARATUS

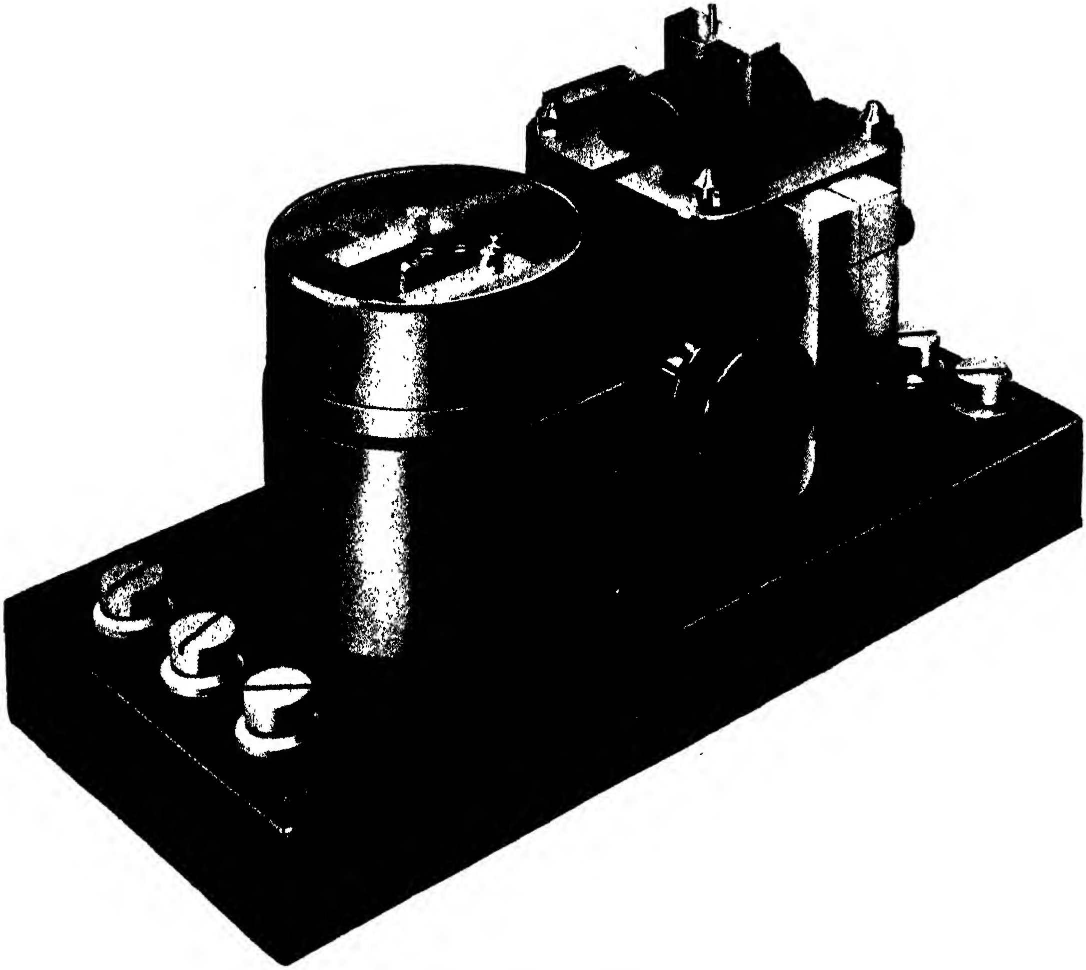
AMONG the exhibits of telegraphic apparatus shown for the first time, the Creed-Murray Multiplex system deserves special attention. This apparatus enables as many as ten separate messages to be transmitted simultaneously and reproduced in the form of a typed sheet.

The signals transmitted through the line consist of + and − currents and spaces, and each letter is composed of a combination of five of these elements. At the sending end of the line typewriter keyboards are arranged to perforate paper tapes with holes corresponding to the signals, and these tapes are passed through the transmitters, which send the signals through the line. At the receiving end the signals operate five selecting magnets, which are arranged to pick out the corresponding letters on a typewriter, while a motor driven cam throws the type bar against the paper and prints the letters. To enable a number of messages to be sent simultaneously, distributors, rotating in synchronism at each end of the line, connect each of the transmitters in turn to its receiving typewriter. By duplexing the line messages may also be sent simultaneously in either direction.

The Murray Multiplex system utilises the capacity of a line to the fullest extent and has many advantages over high speed simplex circuits, as it enables the traffic to be transmitted and distributed with the minimum of delay. The desirability of such a system for wireless telegraphy is apparent, and it is of interest to know that Creed and Co. Ltd. have already utilized the apparatus for this purpose.

Those who have been engaged in developing and perfecting technical apparatus for commercial use will realize what a vast amount of ingenuity and technical knowledge is involved in making an automatic printing telegraph both reliable under working conditions and a commercial success. Although there may be comparatively few of the visitors to the Exhibition who are directly interested in the system as a whole, there is little doubt that a much larger circle would be amply repaid by a careful study of some of the components. For example, the problem of running two distributors in synchronism has been solved by the use of phonic motors, governed by reed vibrators of adjustable frequency, and combined with an intermittent "zero corrector," by means of which the two distributors are kept exactly in step for an indefinite period.

Other features of general interest are the mechanical and electrical relays used in this system. These components have been adopted after much experiment and trial, and the physicist or engineer who is confronted with similar problems may save a great deal of time and labour by studying methods that have proved to be successful in practice.



Creed High Speed Relay

It would enhance the value of the Exhibition if telephone engineers could be induced to follow the example of the telegraphists and display some of the components that are used in connection with automatic telephone exchanges.

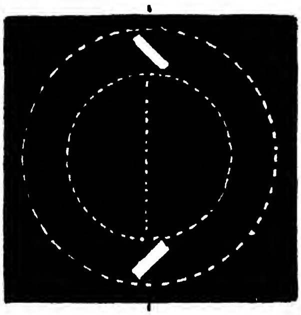
B. S. SMITH.

MICROSCOPES

HITHERTO, the exhibits in this section have been confined to instruments of British manufacture as represented by the firms of C. Baker, R. and J. Beck, Ltd., J. Swift and Son, Ltd., and W. Watson and Sons, Ltd. These four firms again showed examples of their instruments, but on this occasion a welcome addition to the display of microscopes of improved and modern design was made by the presence of many instruments of German manufacture exhibited by Ogilvy and Co., and Carl Zeiss (London), Ltd. The favourable impression

created at the recent Optical Convention of the high standard now attained in the design and construction of modern microscopes, particularly as regards their adaptability to the exigent demands of specialized branches of research both in trade and in academic institutions, was confirmed by a critical inspection of the many and varied types of microscopes and microscopic accessories shown on this occasion.

The undoubted post-war advances in the design of microscopic objectives warrants special reference to a very simple and ingenious method of examining and measuring the performance of an objective invented by Mr Conrad Beck and demonstrated by his firm. This method, which has already been the subject of a communication to the *Transactions of the Optical Society* (**28**, No. 1), does not involve the use of costly apparatus which so greatly militates against the more extended use in private hands of interferometric apparatus; nor are any great demands made upon the skill of the observer from the point of view either of manipulation or of interpretation of the results. The device does not realize as regards ultimate accuracy the results that can be obtained by interferometric methods, but it can be said to place at the disposal of the ordinary user of the microscope a very adequate and elegant means of assigning a definite numerical figure to the state of correction of his



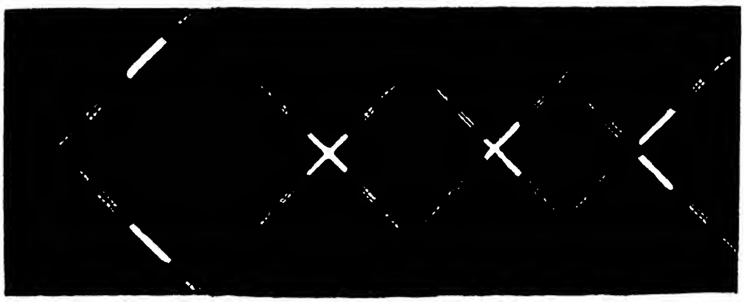


Fig. 1 Fig. 5 Fig. 2 Fig. 3 Fig. 4

objective, accurate enough for most purposes. Stated briefly, the object of the measurements is to determine accurately the position of best focus for particular zones of the lens aperture. This is achieved by inserting behind the lens a diaphragm of the type shown in Fig. 1 in which have been provided two rectangular slits, mutually at right angles to each other, disposed along a diameter of the diaphragm, and each respectively within the zone to be examined, shown by the dotted lines in Fig. 1. As object is used a pinhole selected from a silver film on glass, and strongly illuminated by a wide-angle condenser. Under these conditions each small slit gives rise to a diffraction pattern in the focal plane of the eyepiece as shown in Figs. 2, 3, 4 and 5. At the exact focussing position for the zone under consideration the combined diffraction pattern assumes the form of a symmetrical cross, Fig. 2, and as a departure is slowly made from this position so the respective diffraction patterns move relatively away from each other, arriving successively at positions indicated in Figs 3, 4 and 5. The focussing is performed by moving the eyepiece alone either by means of a rack and pinion draw tube, which is not however recommended, or better, by moving the eyepiece separately on a slide and registering its position suitably against a scale reading to thousandths of an inch. It is claimed for the method that results can be obtained with a probable error of about ·005 inch, and in view of the simplicity of the arrangement it is, in the opinion of the present writer, well worth the attention of those users of the microscope interested in this aspect of the subject.

The firm also showed their well-known models, the "Radial" research and metallurgical microscopes, the "Massive" and the "Pathological" microscopes, together with

miscellaneous illumination and other accessories amongst which was the "Luvex" illuminating magnifier specially suitable for the examination of opaque objects. This is a simple device in which the side of the magnifying glass nearest the eye is silvered to reflect light down upon the object examined, the observation being made through a small hole provided at the centre of the silvering for this purpose.

Reference should also be made to another novelty in the form of 8 mm. and 16 mm. oil immersion objectives of N.A. ·7 and ·25. These were shown by Messrs Ogilvy, and have been designed specially for metallurgical work, in which the elimination of glare both from the front surface of the objective and also from the specimen itself is of some consequence. This firm also showed examples of binocular dissecting magnifiers with neatly interchangeable bodies, and also well designed and made microscopic cameras. Amongst the exhibits of Messrs Zeiss should be mentioned the "Bitukri" binocular tube attachment with obliquely set eyepieces, the Siedentopf "Phoku" photographic eyepiece, the Le Chatelier metallographic microscope, embodying the results of considerable experience gained since the war, and the new Stand E in which particular attention has been paid to questions involving stability, Fig. 6.

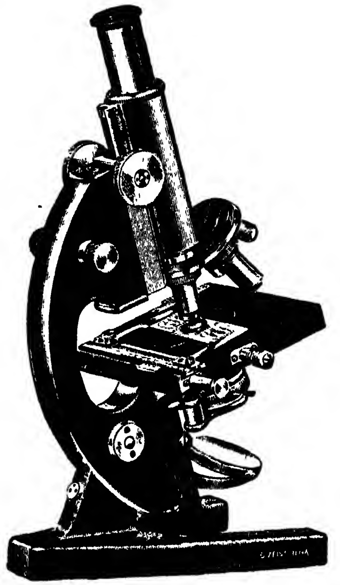


Fig. 6

R. W. CHESHIRE.

PROJECTION APPARATUS

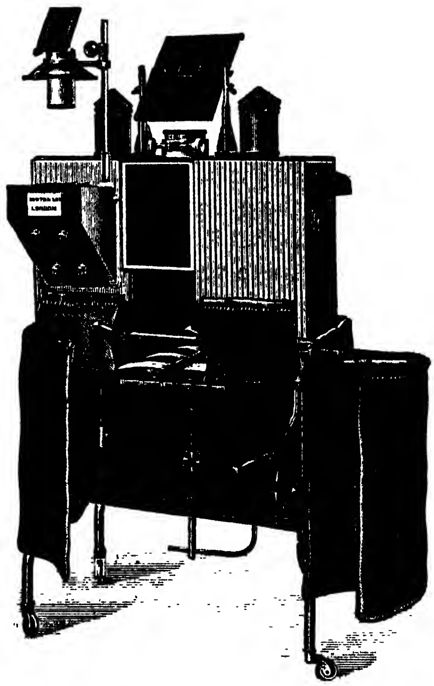
THE importance attached to optical projection for teaching purposes, amusements and scientific work was reflected in the number of exhibits of appliances designed for these varied uses. The instruments shown were all of good quality, and bore evidence of the endeavours of the makers to meet the requirements of all kinds of users. The primary qualities of a good projection apparatus—good illumination, sharp definition and ease of manipulation—were generally well fulfilled; and the improvements on previous patterns plainly indicated the presence of a progressive policy on the part of the manufacturers which augurs well for this important part of the optical industry.

The instruments shown may be conveniently considered under the headings (1) Projection Lanterns; (2) Epidiascopes; (3) Kinematograph Projectors; and (4) Special Appliances.

Projection Lanterns. Exhibits in this class were not numerous, although it is the one most frequently used. Makers are realizing that a lantern made for showing slides only is an out-of-date appliance for teaching purposes, and it is now customary to make provision for the projection of experiments, microscopic objects, etc., in addition. In order to enable such lanterns to be used in schools and other places where an arc lamp is not available, high power gas-filled lamps of the concentrated filament type, fitted with a reflector, are now provided, which are convenient to use and give a satisfactory light for most purposes. The Demonstrator's Lantern and the Vertical Lantern, shown by Newton and Co., and the lantern with micro-projection apparatus of C. Baker, were all well designed and good in performance, illumination and definition both being satisfactory.

It was disappointing to find this class so poorly represented numerically. There is scope for many improvements in detail, so as to render the instrument of more general utility, and it is surprising to note that many makers of optical apparatus do not make a special feature of projection lanterns.

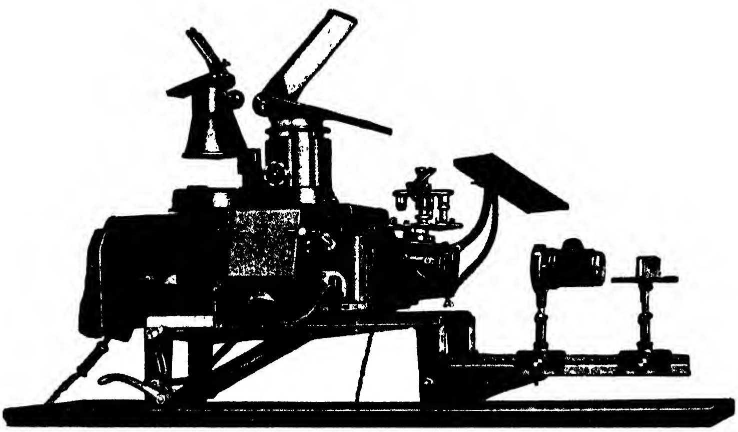
Epidiascopes. The advantages of an instrument for projecting an image of an opaque object on a screen are becoming more fully realized by teachers and others, and epidiascopes were one of the popular features of the Exhibition. All epidiascopes are subject to the inherent difficulty of illuminating the object sufficiently to produce a clear image on the screen, and possess the limitation that a very intense source of light might scorch a diagram or the page of a book which it is desired to protect. In all the instruments on view powerful gas-filled lamps, fitted with reflectors, were used with good results for pictures 4 or 5 feet in diameter; but a more powerful source of light, which could be used without damaging the objects shown, would be an invention which would add greatly to the possibilities of this type of projection.



The "Newton" Episcope. Model C

Most of the instruments exhibited possessed attachments for showing ordinary slides, a simple movement enabling the lamp to be transferred to its new position in the lantern. A further improvement, which need not increase the cost, would be to make provision for the projection of vertical objects, such as the leaves of an electroscope; but this useful feature appears to have been overlooked. With this addition, the instruments shown would cover the greater part of the ground for which optical projection is suited.

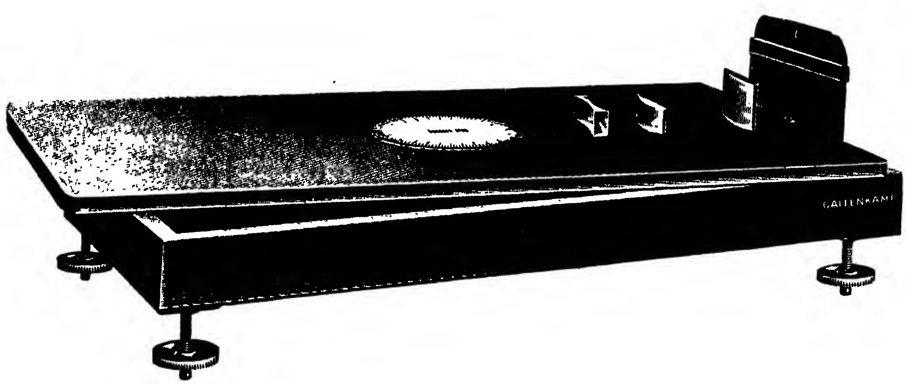
Coming to details of the exhibits, combined instruments for the projection of opaque objects and slides were shown by C. Baker, Gallenkamp and Co. Ltd. (The "Janus"), Ogilvy and Co. (Leitz), C. Garner ("Ica"), and Newton and Co. Simpler types, for opaque objects only, were exhibited by C. Garner and Newton and Co. A more elaborate pattern, designed to perform all the duties of an ordinary projection lantern and an epidiascope, was demonstrated by C. Garner ("Ica"). Extra illumination for badly-reflecting objects was provided in this instrument; and for projecting transparencies an arc lamp replaced the gas-filled lamps.



The Ica Great School Epidiascope

All the instruments on view were well designed, and gave good definition on the screen. Much attention has evidently been given to this form of projection during recent years, with the result that the latest patterns are much more efficient than those of earlier date.

Kinematograph Projectors. The educational possibilities of kinematograph projection are now widely recognized, but a deterrent to the general use of the film projector hitherto has been the elaborate provision necessary to safeguard an audience in the event of a film igniting and causing a fire. This difficulty has now been overcome by designing an instrument on a smaller scale than that employed in public places of entertainment, the source of light being a gas-filled electric lamp, which is automatically dimmed when the film is at rest, and by the introduction of special channels through which the film enters the spool boxes, so that even if a film were to ignite the flame could not spread to the main part on the spools. There are other precautionary devices in these instruments, which meet the requirements of the Fire Inspection Department and may be used in schools. The ordinary size of film may be projected; and although the brightness of the picture is naturally less than in the case when an arc lamp is used, the projection is sufficiently clear for educational purposes or the entertainment of small audiences. A demonstration of the possibilities



Optical Ray Apparatus designed by Professor Bryan

of one of these projectors was given by Houghton-Butcher (Great Britain), Ltd., who showed successfully a film entitled "Power" on each day of the Exhibition. Ross, Ltd., also had on view a projector of this type under the name of the Home Kinematograph Projector; and the same firm displayed the larger type of projector made by them for use in picture palaces, etc., in which the source of light was their high-intensity search-light arc lamp. In all the projectors shown the workmanship was good and the optical parts highly satisfactory.

Special Appliances. Under this heading only one exhibit calls for comment. This was the Optical Ray Apparatus designed by Prof. Bryan, of the Royal Naval College, Greenwich, and made by A. Gallenkamp and Co. Ltd. In this apparatus a parallel beam of light is broken into six narrow beams by passing through slits in a vertical brass plate. The six beams are outlined on a horizontal board, and by placing plates of glass, lenses, mirrors etc. in the path of the beams, the effects obtained are clearly outlined, and the changes in path may be drawn on a sheet of paper pinned to the board. In this way the focal lengths of lenses and mirrors may be measured; and by sliding a plate so as to leave only a single narrow beam experiments with prisms may be conducted so as to obtain indices of refraction, the angles being measured on a circular scale divided into degrees and fastened to the board. As a means of teaching optical principles to elementary students, this apparatus is greatly superior to the use of pins, etc., and should secure a wide adoption in schools.

It is to be hoped that more novelties of a kind useful for teaching will be seen at future exhibitions, as a large part of the output of physical apparatus is absorbed by educational institutions, and any new apparatus of merit aids in the expansion of the industry.

C. R. DARLING.

SURVEYING AND NAUTICAL INSTRUMENTS

THE exhibit of instruments used for the purposes of surveying and of navigation was of the customary high standard. Most of the firms engaged on the manufacture of instruments coming within these categories were represented. E. R. Watts and Son, Ltd., were unable, owing, it is understood, to pressure of work, to take part. On the whole there were not many novelties, but those exhibited were of an interesting character.

Tacheometers. Among surveying instruments, Cooke, Troughton and Simms, Ltd., showed a new tacheometer (Fig. 1) with internal focussing for which it is claimed that the anallatic corrections have been reduced to negligible amounts. A description of the telescope of this tacheometer will be found in a paper by E. Wilfred Taylor, entitled "The Tacheometric Telescope," in *Proceedings of the Optical Convention*, 1926. With this telescope the corrections that have to be made on the value of staff intercept × 100 in order to obtain the true horizontal distance of the staff from the theodolite centre are:

At Infinity	... ...	+ 0·6 inch
,, 250 inches	... ...	Nil
,, 200 ,,	... ...	− 0·25 inch
,, 140 ,,	... ...	− 1·0 ,,

It will be seen from these figures that for all distances for which the tacheometer would be used the correction is absolutely negligible in comparison with the errors made in reading the staff intercept.

The optical arrangements lend themselves to the production of a really compact telescope, the overall length of the body tube in the instrument shown being only a little over 7½ inches. This is a point of considerable importance to surveyors. The telescope must be made to transit at least at one end. It must be pivoted so that it is approximately balanced at its trunnion axis, and the shorter it can be made the smaller clearance space is necessary and the lower is the height of the standard carrying the trunnions. Anything that can be saved here is all to the good, since it permits of a lighter design without sacrifice of rigidity. Further details of interest regarding the telescope of this tacheometer are the large aperture at which the objective works, 1·65 inch, and the fact that it has been found possible to correct it for the sine condition as well as for spherical aberration.

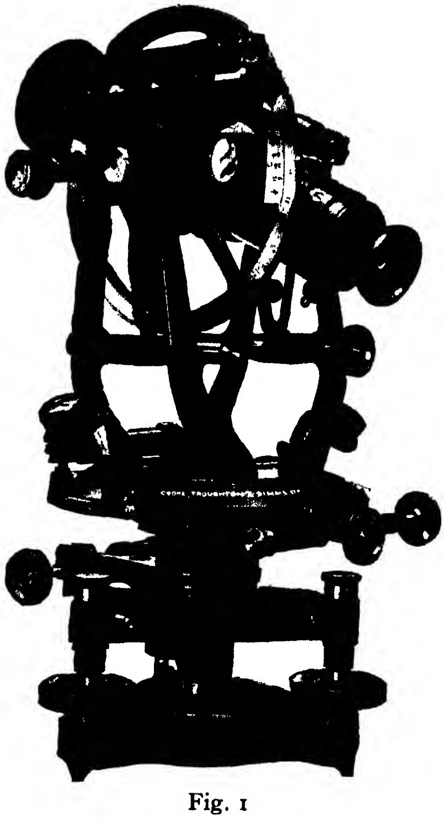


Fig. 1

Another tacheometer embodying some entirely new features was shown by Carl Zeiss (London), Ltd. For this instrument, the staff has to be set

up horizontally and sighted so that it is at right angles to the collimating axis of the telescope when the latter is laid on one end of the staff. By actuating a knurled ring on the telescope tube a second objective is brought into use and the appearance of the field of view is changed to one consisting of two parts separated by a sharp horizontal line. In the upper part of the field appears a portion of the zero end of the staff; in the lower, that part of the staff which subtends the suitable tacheometric angle, say one in a hundred, at the theodolite. The two images are moveable relatively to one another in a horizontal direction by means of a parallel plate micrometer set behind the upper objective. The reading of the staff is thus turned into the coincidence setting used in short base range-finders, a setting which is certainly capable of a higher degree of accuracy than the ordinary method of reading the stadia interval, since in the latter case each wire of the eyepiece must be read against the staff and there is always a possibility of a shift of the staff due to wind or other cause in the interval between the two readings. The telescope is somewhat clumsy in form and of considerably greater overall length (about 13 inches) than the Cooke telescope referred to above.

Apart from tacheometric work the theodolite can be used in the ordinary way. It is fitted with a horizontal circle of 106 mm. and a vertical circle of 80 mm. which are both read through the same eyepiece, the horizontal circle at two places and the vertical at one place only. The circles are divided to 1/3 degree, and the fine reading is made by means of eye-piece scales reading to 2 minutes directly and to finer values by estimation. The magnification of the reading microscopes is however not very great, and it is doubtful whether it is possible to estimate the sub-division to much better than half a minute. The main telescope has a magnification of 24× and aperture of 36 mm. For use as an ordinary theodolite for increasing vertical angles the instrument possesses the disadvantage that the collimating axis of the main telescope does not pass through the trunnion axis, so that corrections would have to be applied to all measurements made. Probably, however, it is intended that the principal use of the instrument should be for tacheometric observations with a staff, and as such it possesses many good features. The instrument, although somewhat cumbrous in appearance, did not seem to be too robust, there being distinct evidences, in the model shown, of damage incurred in transit from Jena to the Exhibition.

Theodolites. Of ordinary theodolites the chief novelties seem to be in the method of reading the circles. There is a general tendency nowadays to get away from the old method of reading the two circles by pairs of microscopes placed at opposite ends of a diameter of each circle. The objections to such a method lie in the risk of upsetting the level of the instrument due to the observer having to walk round it to take his four readings; and to the length of time involved.

In the newer types of instrument the readings are brought to one or possibly two eye-pieces by optical means such that microscopes can be read without the observer having to change his position. Possibly the most notable achievement in this direction is that produced a year or two ago by Messrs Wild, of Heerbrugge in Switzerland, who designed an optical system whereby the scale images at two ends of a diameter are brought into juxtaposition and given relative movements so as to make a coincidence cut. With such a method no carefully fixed fiducial mark is necessary, but only a rough mark to show which division is to be counted, the exactness of position of this mark being sufficient only to allow for the inevitable centering error between the centre of graduation and the mechanical centres. The Wild method has apparently been adopted by Messrs Zeiss in their No. 1 theodolite, an exceedingly compact and substantial looking instrument that should be capable of a high degree of precision. Messrs Wild however seem to have a master claim in their patent for this method of reading, and until an alternative and equally good method is evolved it looks as if they hold the field in this direction. Cooke, Troughton and Simms,

Ltd., have a method, applicable only to a single reading, on which the eyepiece graticule is similar in appearance to an old diagonal scale (Fig. 2). This permits of direct reading to 10″ and by estimation to still finer values.

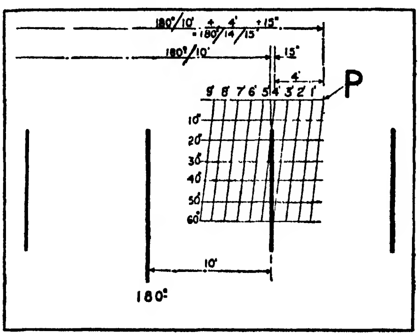
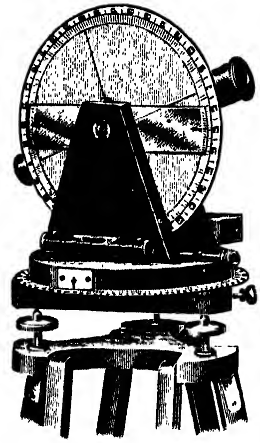


Fig. 2



Student's Theodolite

C. F. Casella and Co. Ltd. showed a theodolite in which the scale divisions at two ends of a diameter are imaged in the same eyepiece and are read by means of an adjustable web actuated by a micrometer head. The same firm also showed a student's theodolite, really little more than a model, and with, of course, no pretensions to high accuracy, that would be invaluable for instructional work in schools. It is a great pity that more practical surveying is not done in schools. There is a great fascination to a boy in being able to produce a real map of an area say half a mile square, to determine heights and distances by triangulation, and in effect to perform with quite a reasonable degree of success all the functions of a trained surveyor. Probably, the reason why such work is not done in schools lies in the fact that the educational authorities are afraid of the expense of the apparatus; and certainly if real instruments have to be bought and put into the hands of boys the objection is a serious one. On the other hand, the instrument maker has not attempted to design simple inexpensive apparatus because there has been no enquiry for it. What Messrs Casella have done with a model theodolite is equally possible with a level, a tacheometer or a sextant, and it should be by no means difficult to produce in quantities semi-accurate models of all these instruments at a cost of two or three pounds apiece. Could not the Department of Scientific and Industrial Research commission two or three firms to make such instruments, and then give a demonstration to the Board of Education to show their value for educational purposes?

Levels. There was nothing entirely new in the way of levels shown, but most of the surveying instrument makers showed various types, with suitable arrangements for viewing the bubble either in the telescope or from the eyepiece end of the telescope. There were also a number of reversible levels on show.

Among minor details connected with surveying instruments Messrs Cooke, Troughton and Simms had on exhibition a model to illustrate the difference between a ground-in and a scraped centre. In the process of grinding-in a very small amount of the abrasive necessarily remains embedded in the surface of the metal. In time this abrasive will cause wear and slight slackness of fit, and it is claimed that with a scraped centre the remnant of abrasive is removed and a more lasting fit obtained. At Messrs Casella's stand was to be seen a model of Buchanan Wollaston's Patent Calculator, an instrument which performs the functions of slide rule, proportional compasses and protractor. It is stated that its

performance as any one of these instruments is superior to the usual forms, but such a claim is probably over optimistic.

Nautical Instruments. Nautical instruments were rather poorly represented. Henry Hughes and Sons, Ltd., showed a series of sextants of various types, including a new type of micrometer sextant, but the particular instrument exhibited was so badly out of adjustment that it was not possible to form any just idea of the accuracy likely to be obtainable with it.

There is in fact not much encouragement at the present time for any firm to bring out new designs of nautical instruments. The shipping trade is still bad, and as long as that is the case the demand for instruments and the desire for instruments of a new type can be only small. There is a further discouragement in the fact that the sailor is very conservative, and has it firmly fixed in his mind that because his apparatus has always been made in such and such a way that way must necessarily be the best. Progress under such circumstances must be slow. There is however evidence that new ideas are taken up even among sailors. The Echo Sounding Gear designed at the Admiralty Research Laboratory and now manufactured on a commercial scale by Henry Hughes and Sons, Ltd., is being installed in ships in steadily increasing numbers, and there is no doubt that the ability to obtain soundings practically instantaneously in comparatively deep water is a great boon to navigation. In the saving of time, as compared with the old fashioned type of sounding machine, in which the depth recorder had to be lowered to the bottom of the sea and then laboriously hauled to the surface again, the new gear is a wonderful improvement.

In addition to their nautical apparatus Messrs Hughes showed a series of instruments, mainly for warfare purposes, used in aeroplanes. Among them was an "Enemy Speed Finder" used to enable the pilot of a torpedo carrying aeroplane to obtain the speed at which the target ship is moving. The general principle of this instrument is comparatively simple. A series of parallel wires are stretched across a circular hole which is maintained as nearly as possible horizontal. The aeroplane is flown so as to travel at right angles to the enemy's course and the wires are set in the machine so that they also are at right angles to the same track. By using a peep sight at a suitable height above the grid the lines of sight to the wires, if continued downwards to the sea surface, would cut the latter in a series of fixed parallel lines all at right angles to the enemy's track. By counting the number of these wires that are crossed by the target in a certain interval of time and taking account of the height factor the speed is easily and quickly obtained. In theory, the instrument certainly appears to meet all requirements. In practice its accuracy will depend upon the degree of steadiness with which the grid can be maintained horizontal and the degree of accuracy with which the pilot can determine his actual drift due to wind. Obviously if the aeroplane has any velocity component at right angles to the grid wires, relatively to the water, the projections of the lines upon the sea surface will be not fixed but moving, in which case the counting of the number of spaces traversed must entail error in the determination of the enemy speed.

T. Y. BAKER.

PYROMETERS AND TEMPERATURE MEASURING APPLIANCES

THE manufacturers of pyrometers put up an excellent show. The feature that impressed the visitor who studied the instruments in detail was the evidence of improvement in design of standard types of instruments rather than the appearance of radical departures from existing practice.

A number of firms exhibited resistance thermometer outfits intended for the measure-

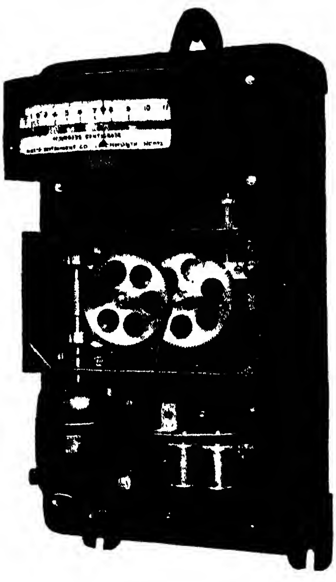
ment of the temperature of cold stores, oil tanks, etc. It appears to be now generally accepted that, when a fairly high degree of precision in industrial temperature measurements is desired, and the temperatures are moderate, the resistance type of instrument is the one to employ. Its only serious competitor for this class of work is the mercury-in-steel type, which however is not applicable to cases where the distance between the bulb and the dial exceeds 100 ft., nor can several bulbs be connected to one indicator. On the other hand, the mercury-in-steel thermometer has the advantage of ruggedness, and no maintenance cost as regards batteries.

The Cambridge Instrument Co. Ltd., Siemens Bros. and Co. Ltd., Negretti and Zambra, John J. Griffin and Sons Ltd., the Foster Instrument Co., and the Bowen Instrument Co. showed representative outfits of the resistance thermometer type. Many of the outfits were fitted with the press button form of switch where connection to the appropriate thermometer circuit is made through point contacts between flexible strips. In some of the outfits considerable ingenuity had been displayed in the arrangement of the circuits behind the switchboard, with a view to simplicity of installation and of adjustment. This is a commendable feature. The designs of the various thermometer bulbs are worthy of detailed study, for some of them represent distinct advances.

Another feature to which attention may be directed is the nature of the methods employed for compensating for the resistance of the leads. A number of the instruments shown employ the three-lead system which was originally devised by Siemens in the very early form of resistance thermometer.

In thermo-electric pyrometry the notable feature was the recorders. Most of the firms exhibiting had given thought to the question of accessibility and greater ruggedness of construction. The Cambridge Instrument Co. showed a simple, inexpensive recorder for use with a base metal thermocouple. In this instrument a pivoted coil galvanometer is used. The "pyro" temperature recorder exhibited by the Bowen Instrument Co. had several noteworthy features and is described in detail in the *American Machinist* for December 11th, 1926.

The Foster Instrument Co. exhibited a furnace controlling device based on a thermo-electric pyrometer of the base metal type working through an indicator and operating a "hit and miss" control of the oil supply to the furnace burner. The pyrometer indicator is of the usual type, but having the "Resilia" pivot mounting; this appears to have peculiar advantages in connexion with the method of operating the control, which is by a periodic depression of the pointer. The cycle of depression and elevation is about 10 seconds. When the temperature exceeds any desired figure, which is adjustable at will, the depression of the pointer closes the primary circuit of an electro-magnet relay; and the consequent closing of the secondary circuit of the relay closes the oil valve to the furnace. The depression mechanism is driven by a small electric motor and a system of reduction gearing. A point of interest in this arrangement is that the gear box mechanism has only an operation which might be termed permissive, in that it periodically releases a detent, against the force of a spring, thus allowing a presser bar to depress the pointer under the influence of a relatively small force of gravity. Thus, although the gearing is robust and operated with large forces which should make it reliable, the forces effective

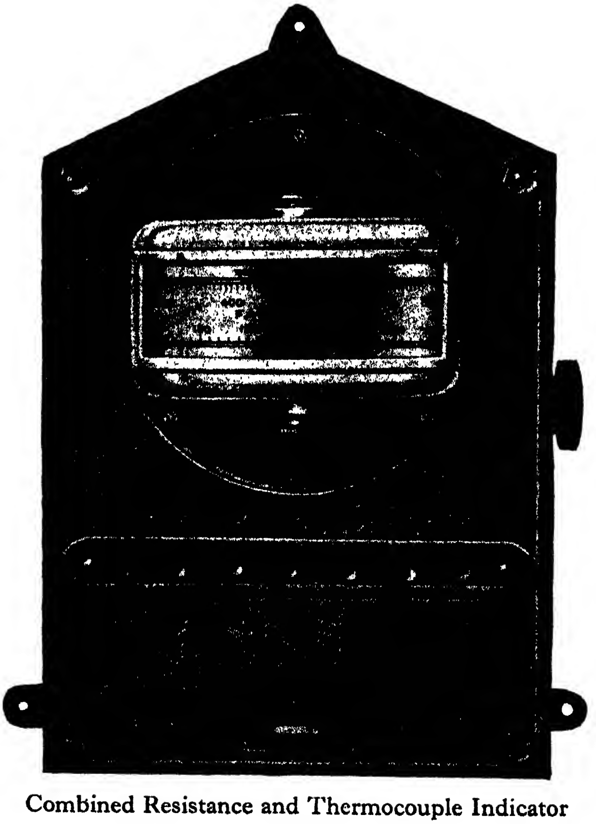


Foster Instrument Co. Furnace Control Device

in the indicator are of the proper small order to prevent damage to the relatively delicate parts in the instrument.

Another interesting feature of this automatic control is the "broken couple alarm." The correct operation of any system of control of this kind depends, of course, on the continuity of the circuit in the thermocouple itself. With this system, when the thermocouple breaks, the pointer is automatically moved up beyond the top of the scale, thus signalling the breakage, and, at the same time, through an extra pair of contacts in the indicator, operating to check the heating till the thermocouple is replaced. Without some such device the failure of the thermocouple would cause the pointer to move down towards zero and thus the automatic mechanism would tend to increase the heating in the furnace. This alarm system is achieved by bringing on to the thermocouple circuit, at the head of the thermocouple itself, an E.M.F. from the 4-volt accumulator (which works the rest of the control apparatus) through a suitable high resistance. This results in a small extra current flowing in the thermocouple pyrometer circuit, where it is presented with a parallel path in which the thermocouple itself is in parallel with the connecting cable and the indicator. The thermocouple being of very low resistance compared with the indicator and the cable, the bulk of the current from the accumulator passes through the thermocouple, and only such a small fraction through the indicator that its effect is negligible. This small effect is taken into account in the zero setting of the indicator. The whole effect on the indicator being small (while the thermocouple is intact) any change in the E.M.F. of the accumulator is itself negligible.

When the thermocouple breaks, the whole of the small current from the accumulator must pass through the indicator itself and is there so arranged as to carry the pointer beyond the upper limits of the temperature scale, thus signalling the failure of the thermocouple.



Combined Resistance and Thermocouple Indicator

A novel feature of Messrs Negretti and Zambra's stand was the combined resistance and thermocouple indicators. These had two ranges, one an open range for low temperature work from 10° to 150° C., for example, and another from 100° to 600° C.

Messrs Siemens Bros. and Co. Ltd. showed, in addition to other exhibits, a thermo-electric form of potentiometer suitable for workshop use. The idea underlying the design of this instrument is the balancing of the E.M.F. to be measured by the potential drop in a circuit, the current being measured on a robust milliammeter when balance is obtained.

For high temperature measurements the disappearing filament type of pyrometer has now secured premier place. The Cambridge Instrument Co. showed an instrument embodying the latest features, and it is noteworthy that the precision in reading attainable with this type of instrument is now such as to justify the use of a potentiometer and shunt for measuring the current through the pyrometer lamp, instead of the less accurate direct-reading ammeter.

A Laboratory Standard optical pyrometer was shown in use as one of the exhibits of the National Physical Laboratory.

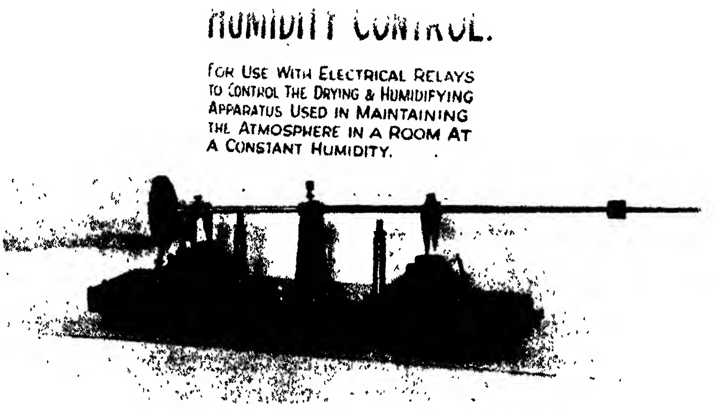
Messrs Siemens, who were amongst the earliest manufacturers of disappearing filament pyrometers, exhibited a new model with a novel form of leather case for carrying both the instrument and its auxiliaries.

Messrs P. J. Kipp and Zonen showed some interesting forms of total radiation pyrometers. The radiation is measured by means of a Moll thermocouple of 18 elements of constantan-manganin. This is in the form of thin strips about 3/10 mm. wide and ·007 mm. thick. The tube is fitted with diaphragms, and the end nearest the furnace has a water-cooled diaphragm.

EZER GRIFFITHS.

RESEARCH SECTION

THE annual Exhibition of the Physical and Optical Societies grows in scope every year. Last year a fresh step was taken by the introduction of a Research Section which proved remarkably successful. In its second year this section has grown in extent and has fully



Humidity Control. (British Research Association for the Woollen and Worsted Industries.)

sustained its interesting character. Contributions, 72 in all, were received from nineteen sources, corporate or individual, and the total effect was to give a representative view of British research which was certainly impressive. If a desideratum may be mentioned, it is that one would wish to see the work of our University laboratories more fully represented in future in this section. It was a pleasure to note the delightful air of informality and

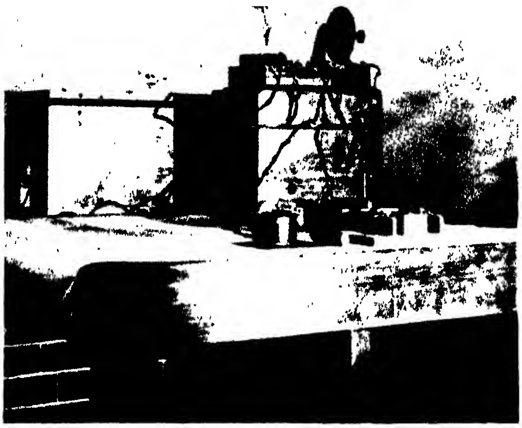
friendliness pervading the exhibition, expressing that eagerness and generosity of spirit which true research seems always to create. It is not possible to touch on all the items shown, and it is with no invidious intent that the writer of these notes records his impressions of just those items which happened to strike his attention in a visit of finite duration.

There is evidence of the growing use of photoelectric photometry. The British Photographic Research Association showed an improved model of their photometer for measuring the opacity of photographic negatives. The selenium cell previously employed has given way to a special gas-filled photoelectric cell, and the difficulties attending reference to a standard of comparison have been well negotiated. Again the British Thomson-Houston Co. Ltd. showed how, by means of a gas-filled photoelectric cell working at its ionization point, the flicker of lamps in A.C. circuits can be measured. We shall refer later to the photoelectric method used by the General Electric Company, Ltd., for the rating of electric lamps. The same company also showed stages in the construction of the flat annular type of photoelectric cell.

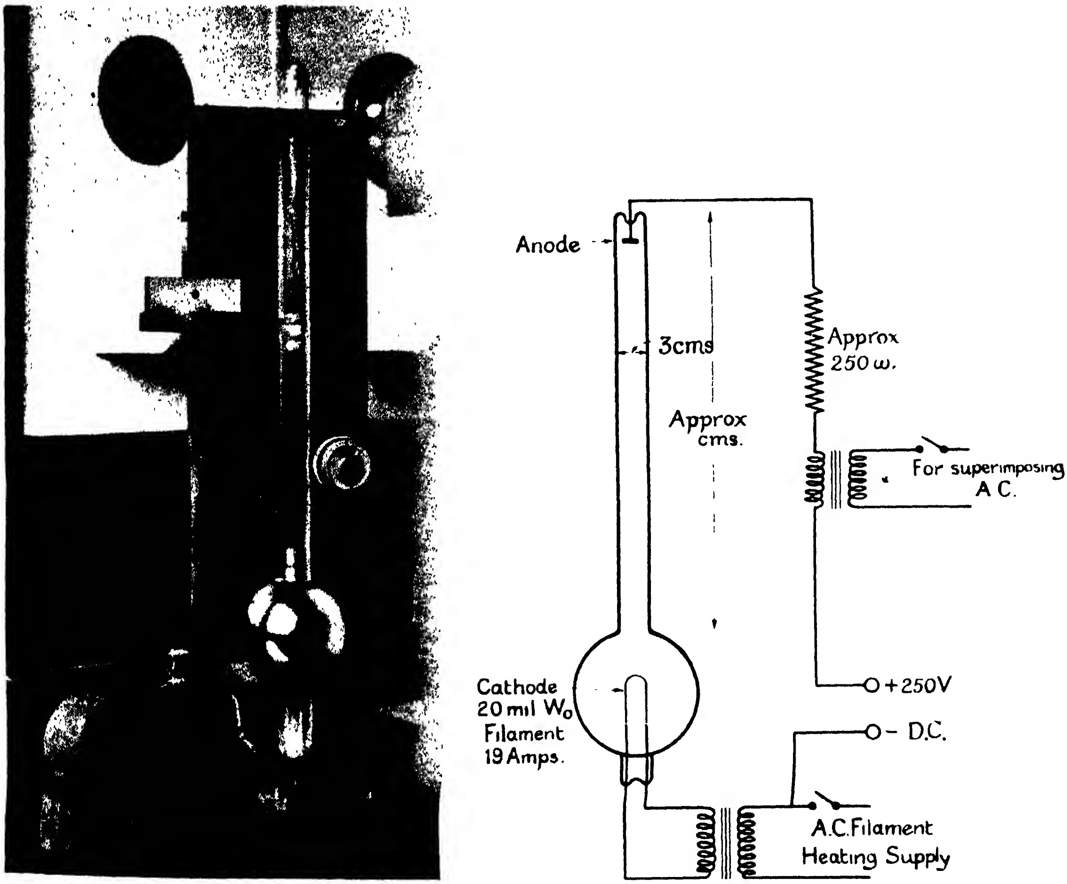
In the exhibits of the British Research Association for the Woollen and Worsted Industries were to be seen admirable examples of the application of scientific methods of control of the physical conditions governing the treatment of fabrics in the factory. The apparatus for controlling the humidity of the air and for measuring the moisture content of fabrics appeared both simple and effective. Of the exhibits shown by the Henley Research Laboratories, especially striking were the series of experiments, made in collaboration with Mr G. L. Addenbrooke, showing the motion of liquid dielectrics in divergent electric fields. Many years ago J. W. Swan, and later Lord Armstrong, made extensive observations on the effects of electric fields on solid and highly viscous liquid dielectrics. They demonstrated, without, however, explaining, surface patterns remarkable for their complication and yet beauty of detail. In the present experiments the important part played by minute amounts of residual moisture has been well shown. The subject is clearly of much significance in relation to the important problems of the strains occurring in the dielectric of high-voltage cables. The Metropolitan Vickers Electrical Company's Research Department showed some interesting exhibits of metallic zirconium and its alloys, and an electric furnace employing molybdenum wire, which can be operated up to 1800° C. Samples of metals plated with chromium showed that bright silver-like appearance which persists even after long exposure to ordinary atmospheric conditions. A series of thermionic valves showed the short-pattern principle of construction employed by this firm with the object of reducing positive ionization and securing low impedance. Protection from corrosion was also the subject of exhibits by Dr G. D. Bengough and Mr Stuart, in regard to surfaces of aluminium and duralumin, the process used here being anodic oxidation.

The exhibits of the Brown-Firth Research Laboratories illustrated the development of the iron-chromium and iron-chromium-nickel non-corrodible steels, and demonstrations were given of some of their special mechanical characteristics and applications.

Dr E. W. Marchant showed his alternating current bridge method of exploring the conductivity of metal plates and of showing up defects in them. The balance of the bridge is upset when a search-coil in one arm is placed in proximity to the plate. It is possible to destroy the balance of an A.C. bridge by changing either the resistance or the inductance (or capacity) in one arm. The pair of attendant out-of-balance E.M.F.'s are necessarily in quadrature, and it is interesting to observe how these can be isolated and separately measured. This is done by the use of a synchronously driven commutator, with a direct-current galvanometer in the detector arm of the bridge, so that according to the setting of the brushes of the commutator, either component alone may produce its effect, as desired. The resistance component is found to be the more suitable for the testing of plates of magnetic material, and the inductance component in the case of non-magnetic materials.



Apparatus for testing conductivity of plates with large coils removed from and standing in containing box. Large coil is shown on plate to left. Small coils for detecting fine cracks are lying on the table. A test piece on a support is shown on right with coil in position. The test piece is rotated and the crack is indicated by reduction in galvanometer deflexion. Small rotary converter and commutator are contained in box behind the instrument (Dr E. W. Marchant).



New Type of Electric Discharge Tube (British Thomson-Houston Co. Ltd.)

None of the exhibits was more striking than one entitled "A New Type of Electric Discharge Tube" shown by the British Thomson-Houston Co. Ltd. The tube is of glass, about 20 inches long by $1\frac{1}{2}$ inches in diameter, and is set vertically, with a tungsten cathode electrically heated at the lower end, which is expanded slightly into a bulb, the anode occupying the upper end. It contains argon at a few millimetres pressure, and under a fall of 20 volts across the tube a rosy discharge (the uniform positive column) fills the tube, save an annular space next to the glass walls, ascribable to a charge on the walls. On switching off the cathode heating current for a moment the drop of temperature of the filament causes a rise of potential across the tube, and a sharp bombardment of the cathode by positive ions ensues, causing a cloud of tungsten to ascend in a green column from the cathode. The effect of a transverse magnetic field on this column is remarkable. When the pole of a bar-magnet is brought up to a point on the wall of the tube the rising column reaches that point but is unable to rise higher. If the magnet is withdrawn the column resumes its movement and rises like a viscous liquid, its green colour being manifested along the whole length of the tube. On again bringing up the magnet to any point of the wall a new discharge appears to originate near the boundary of the positive column and to pass transversely across the tube. It has the appearance of a fine beady bright-red line. On superposing a small low-frequency alternating voltage in the main circuit of the tube this line of discharge is converted into a series of curves of sine form. The effect was first observed by Langmuir in the course of the researches, which he has recently been engaged upon, on the electrical discharge in gases at moderately high pressures (*Electrical Review*, Nov. 1924). This firm also showed a mechanical model of the actions occurring in an oscillating valve circuit. A weighted pulley represents the inductance, and a spring the capacity, whilst a supplementary cord connecting the spring with the centrifugal governor of the driving motor represents the "feedback" which maintains the circuit in oscillation.

Mr A. F. Hallimond exhibited a form of magnetic separator for research on powdered minerals. The dry sieved powdered material is resolved into three portions by the successive attraction of two magnets of unequal strength, the stronger coming second. Mr H. Dewhurst demonstrated the action of the sputtered film bolometer which he has recently produced (*Proc. Phys. Soc.* **39** (1926), 39). On a collodion film of the thickness of a wavelength of light is deposited in an electric discharge tube a still finer film of bismuth, forming a narrow bridge across the collodion between two metal terminals; and this is finely smoked over. The film was shown to respond rapidly to the incidence of radiation, and results of its application in the future will be awaited with interest. Professor W. Cramp of Birmingham University showed a simple magnetic balance made by one of his research students, Mr W. P. Conly. The design is of interest as permitting the force on a short length of conductor placed in the magnetic field under test to be measured, whilst neutralizing the effects of the forces on the adjacent portions of the circuit. (*Journ. I.E.E.* **61**, Jan. 1923.)

The Air Defence Experimental Establishment showed the Webster Phonometer, an instrument which is portable and yet delicate enough to determine the comparative intensities of distant sources of sound, such as fog-sirens. The Sound Locator Training instrument is the same as the instrument shown last year, except for the important addition whereby the sounds in the telephones worn by the pair of operators are locally generated. Facility in the use of the instrument can thus be acquired, the task being to point the locator at a hidden dummy target running on a track indoors. The Research Association of British Rubber and Tyre Manufacturers showed an apparatus for the rapid detection and estimation of grit in fine powders.

We have yet to add our impressions of the exhibits, remarkable for their number, variety and high interest, which were shown by three great centres of physical research in this

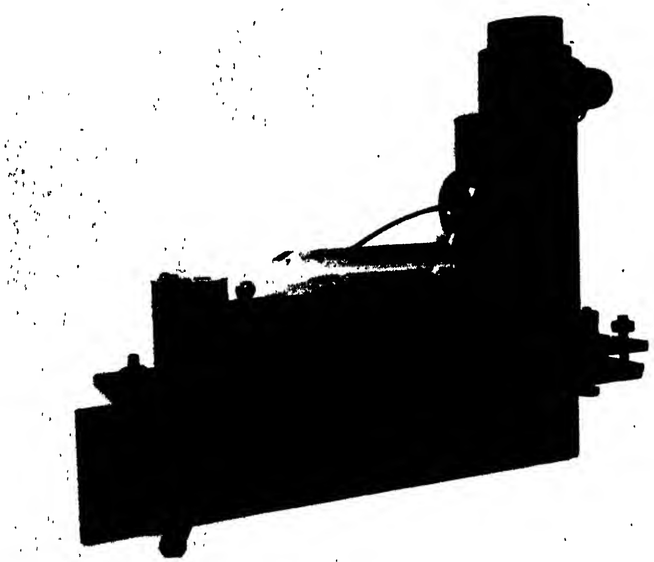
country. Beginning with the exhibits from the Admiralty Research Laboratory, we shall refer first to the Phonic Motor. The importance of this device for the accurate determination of time-intervals, long or short, is now fairly generally appreciated. Thus far the accuracy has rested on the constancy of vibration of the controlling tuning fork. In the present exhibit this fork (50 periods per sec.) is itself controlled by electromagnetic impulses received every second from a standard clock. The period of the electrically driven fork increases very slightly with amplitude, and thus a range is provided, narrow but sufficient, in the limits of which it is possible for the fork automatically to take up a period which is an accurate sub-multiple of the standard second. Under the heading of Sound Ranging Apparatus was shown an interesting method of observing the reception of under-water shocks or vibrations incident on a steel diaphragm, the movement of which operates a contact mounted on an inertia wheel, with spring control. The commencement and termination of the disturbance are recorded by the phonic wheel (or by a string galvanometer). There is an error of time-lag to which experiments of this kind—for example, Regnau. 's determinations of the velocity of sound in gases—are well known to be subjected; and it is the merit of the device mentioned that this error is compensated and so largely eliminated.

The Frequency Standard for high sonic frequencies is intended to measure audio-frequencies above the limit—say 2000 per second—within which tuning forks are practicable. In place of transverse vibrations longitudinal vibrations are substituted. A steel rod clamped at its centre is struck at one end. The longitudinal vibrations excited are communicated to a microphone situated close to the other end, but just out of direct contact with the rod, so that currents of the same frequency are generated in the circuit of the microphone. If the alternating current of high audio-frequency, to be determined, is fed into the microphone circuit, the difference in tone may be heard in a telephone included in the circuit; and if the standard rod is suitably chosen, this tone will lie within the range of maximum sensitivity of the ear for pitch, and can be determined by a monochord in the usual manner. The Alternating Current Potentiometer was shown in its connection with a special research. At the hands of its author, Dr C. V. Drysdale, it has found an interesting application on a large scale to the measurement of the magnetic field round an under-water cable carrying an alternating current. The use of the phase-shifting transformer has proved most apposite in this work. The surprising extent to which the field is distorted owing to the conductivity of the medium surrounding the cable may be seen in the original paper (*Phil. Trans. R. S.* ser. A, **65** (1923)). Connected with this is another exhibit, a Double Differential Vibration Galvanometer, in which the effect of capacity currents is eliminated by splitting the moving coil, so that the capacity currents in each half neutralize, whilst the out-of-balance currents in the bridge which is employed produce their proper effect as in the usual single coil instrument.

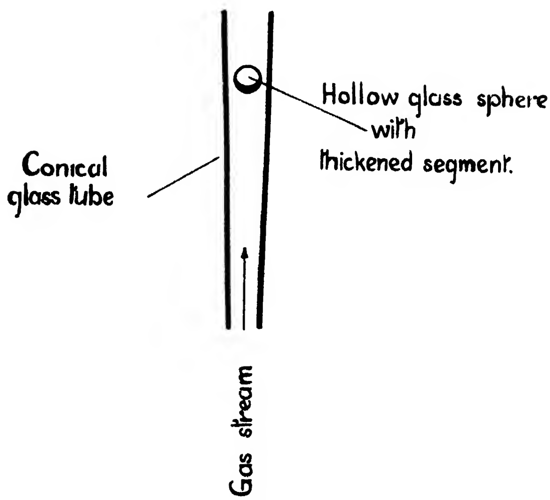
Passing to the exhibits of the Research Laboratories of the General Electric Company, Ltd., we come to a machine for the voltage rating of incandescent electric lamps. The action depends on the matching of the intensities of the light from the two halves of its spectrum, which may be referred to roughly as the red end and the blue end. Not that any production of an actual spectrum is effected; the selection is performed by two photoelectric cells, containing respectively rubidium and sodium, the former responding mainly to the red end, the latter to the blue end of the spectrum. The currents excited in these cells by a lamp at the correct standard temperature are made to produce a null effect on the leaf of a gold-leaf electroscope. The voltage on any lamp under test is adjusted until the electroscope signalizes the same balance of its spectrum, and therefore the attainment of the required temperature of operation. The method is expeditious, and the tests were seen proceeding at the rate of two or three lamps per minute, records of course included.

An exhibit relating to the structure of Opal Glass was very instructive, showing how the

opalescence is determined by the presence of small diffusing particles in a clear matrix. For a given total amount of diffusing material, *e.g.* calcium fluoride, the glass may either diffuse the light completely or be undesirably transparent, according to the size of the particles. One sample of glass was shown which is clear to infra-red radiation ($\lambda = 2\mu$), while it completely diffuses visible light.



Flowmeter for Liquids (General Electric Co. Ltd.)



Ewing Ball and Tube Flowmeter for Small Gas Flows

Interesting models were shown of a sensitive electroscope and a new type of level, both depending on the use of a vertical loop of fine tungsten wire with the vee uppermost, and so dimensioned or loaded as to be nearly unstable, and thus extremely sensitive to transverse forces. By rotating the loop in its own plane the sensitivity can be controlled. Owing to the fineness of the wire used the loop is practically deadbeat in ordinary air. The apparatus for comparing the expansion coefficient of glass rods, shown last year, has now been im-

proved by the introduction of a quartz rod, thus allowing the absolute expansion of glasses to be determined. A flowmeter for liquids was shown, depending on the principle that the dimensions of the parabolic jet emerging horizontally from a narrow orifice are simply related to the velocity of efflux. A further account of this instrument seems desirable.

Two demonstrations of interest consisted of reproductions of effects obtained in other laboratories. One of these was the Boucherot network, a very simple means of obtaining a constant current from a fixed A.C. supply, in spite of wide variations in the impedance of the load. The load is placed in parallel with either the capacity or the inductance in a combination of these in series, and adjusted to resonance across the mains. The second showed the magnetic control of the plate-current of a diode thermionic valve. As A.W. Hull has shown, the electronic emission can be suddenly reduced to zero by increasing beyond a certain critical value the magnetic field parallel to the filament, the anode being a coaxial cylinder. From the observed values of this critical field, and of the plate voltage and the radius of the cylindrical anode, the ratio e/m for the electron can be calculated. The experiment deserves to find a place in any advanced laboratory course for electrical students.

In conclusion, there were the exhibits shown by the National Physical Laboratory. Dr D. W. Dye gave us the opportunity of seeing a further stage in the development of the system of determining frequencies by the aid of the Abraham Multivibrator. The accuracy of the method rests on the constancy of frequency of the master tuning fork, which is valve-maintained. For most practical purposes this is beyond criticism. It appears, however, that it is possible to control a tuning fork by electromagnetic impulses received every second from a standard clock, thus making the period of the fork an exact submultiple of one second. How this result is achieved is a matter of some theoretical interest. We have already referred to a method of controlling the phonic motor from a standard clock through the intermediary of a tuning fork; but the physical processes involved in the two cases do not appear to be identical. In its present form the method was shown as a means of supplying standard telephonic frequencies. We imagine the extension of the idea to radio-frequency measurements is on the way.

Dr Ezer Griffiths and Mr Awbery exhibited a simple flowmeter for small gas flows (from 5 c.c. to 40 c.c. per sec. in the actual apparatus shown). The ascending gas current along a conical vertical glass tube, widening upwards, supports a light hollow sphere of glass, the position of equilibrium of the sphere indicating directly the rate of flow of gas.

Of particular interest was the quartz oscillator used for measuring the velocity of sound in a gas, an application of the piezo-electric crystal which was first made by Prof. G. W. Pierce of Harvard. The method consists in the production of stationary sound waves between the face of the oscillating crystal, excited by connexion in a suitable valve circuit, and a moveable plane reflector set parallel to that face. When the distance between the surfaces is an integral number of half wave-lengths, resonance of the included air-column occurs, and this reacts on the amplitude of vibration of the crystal and so on the plate current of the valve, the maxima being sharply indicated. In the apparatus shown this principle is applied by Dr Griffiths and Mr Awbery to the determination of the percentage of carbon dioxide in a gas. The quartz employed has a frequency of 40,000 per second, so that the sound waves generated have a length of about 8 millimetres.

Two pieces of apparatus were shown for the measurement of thermal conductivities; one by Dr Griffiths applying to metal rods; the other by Dr G. W. C. Kaye, designed for the measurement of the conductivity of vitreous silica. The former is a continuous flow method, in which the heat loss from the sides of the rod is eliminated by surrounding it with a coaxial jacket with the same temperature gradient as the rod itself. The latter employs the "divided-bar" method of Prof. C. H. Lees, either air film or liquid film contacts being employed. The apparatus is mounted in a thermostatic enclosure, the

temperature of which can be varied over the range 50° C. to 250° C. In both methods the heat input is produced electrically, and the temperatures measured by thermocouples. Dr Kaye also demonstrated the methods he has recently evolved for measuring vacuum pump speeds, and showed a simple experiment illustrating the sensible differences of pressure than can exist in vessels separated by even a short length of narrow glass tubing.

The sound-pulse photographs of Dr A. H. Davis and Mr N. Fleming illustrated well their use in predetermining the acoustics of a building. Small-scale models of the building are constructed, in which a small spark gap is placed to represent the source of sound. A further example of the use of small-scale models was seen in the exhibit of Mr J. W. T. Walsh. The effect of structural alterations on the natural lighting of a room can thus be rapidly studied with the aid of a portable photometer.

D. OWEN.

BRITISH INDUSTRIES FAIR, 1927

We have received from the Department of Overseas Trade a list of manufacturers of optical and other scientific instruments who are exhibiting at the British Industries Fair this year. The Fair, which, as before, is to be held simultaneously in London and Birmingham, takes place on February 21st to March 4th, and the London section will be at the White City.

The Scientific and Optical section in London, which appears to be a strong one, comprises exhibits by many well known instrument makers, including Messrs Cooke, Troughton and Simms, Ltd., Ross, Ltd., Short and Mason, Ltd., Houghton Butcher, Ltd., Ogilvy and Co., T. A. Reynolds, Son and Co., Wray, Ltd., W. Harling and Co., and several of the ophthalmic manufacturers.

REVIEWS

Handbuch der Physik. Band I: Geschichte der Physik Vorlesungstechnik. Redigiert von Karl Scheel. Pp. 404 with 126 illustrations. Julius Springer (Berlin). Price Reichsmark 31.50, or Reichsmark 33.60 bound.

The volume under consideration is the first of the new *Handbuch der Physik* which is now in process of publication in Germany, though it is not the first volume which has appeared. Its subject matter is somewhat different from what we are accustomed to expect in works of this character, so that together with one or two other unusual volumes, it enables the *Handbuch* to be considered as a complete encyclopaedia of Physics.

The first portion of this volume consists of the history of Physics up to 1895, by Dr Hoppe, from whose larger work it was probably condensed, though the arrangement is different. The history of Physics is a subject to which whole volumes could be devoted. That a history with pretensions to thoroughness has been produced in about 180 pages, is a tribute to the literary ability of the author as well as to the extent of his knowledge and researches. An attempt has been made to give a brief reference to all the important events in the history of Physics. The multitude of facts presented is very great, while the references to original sources amount to probably more than 1500. In spite of this the work is much more readable in the ordinary sense than one would imagine, though it will probably be used for reference rather than for continuous reading.

In spite of many excellences which we are happy to say outweigh the defects, there are a number of omissions that must be regarded as serious in view of the completeness with which the author has accomplished his task. In particular, we cannot agree that one minor reference to Kelvin's work is sufficient as regards his contributions to thermodynamics. His great memoir of 1851 in

the *Transactions* of the Royal Society of Edinburgh is not mentioned, though in it, after acknowledging the priority of Clausius as regards the second law of thermodynamics, he made several important theoretical advances. Nor do we find any reference to the Joule-Thomson effect, while the first calculations on the molecular velocities made by Joule in 1847 are ignored, similar calculations performed by Clausius in 1850 being quoted instead. There appears to be no reference to Maxwell's work on the distribution of molecular velocities.

The author consistently refers to Boyle's Law as Townley's Law. There are many disadvantages attendant on the use of personal names in connection with scientific discoveries into which we cannot enter here, but the substitution of Townley's name for that of Boyle does seem to call for comment. The facts appear to be that, as the author shows, Townley formulated the hypothesis that the pressure is inversely as the volume and that he communicated it to Boyle who informs us that the "ingenious Gentleman Mr Richard Townley...endeavoured to supply what I had omitted concerning the reducing to a precise estimate how much air dilated of itself loses of its Elastical force.... But because he hath not yet, for ought I know, met with fit Glasses to make on any-thing-accurate Table of the Decrement of the force of dilated Air, our present design invites us to present the reader with that which follows" (viz. experimental results, and a confirmatory test of the hypothesis).

It seems clear therefore that Townley, appreciating Boyle's work, made the suggestion but neither took pains to test his hypothesis nor even to publish his results. If one physicist takes the trouble to verify the suggestion of another who apparently takes no further interest in it, then we are of opinion that if any name is attached to the resulting discovery or law it should be that of its verifier who may not have conceived it but who had all the trouble of bringing it into the world.

We think that it is rather a hasty and unscientific generalization when in considering Mariotte's association with Boyle's Law, Dr Hoppe writes "dass er Boyle und Townley nicht zitiert, beweist bei einem Franzosen bekanntlich nichts."

More than one-half the references are to German papers, so that the work is a history of Physics, as it were, through German spectacles. This is to be expected and is just such a criticism as could probably be made against an English or French history of Science. It need not be a demerit so long as it is honest and may be of use to foreign readers as showing that their own estimate of their great men is not necessarily universal.

The latter half of the book—Vorlesungstechnik—is descriptive of a series of experiments designed to illustrate the principal phenomena of physics. This portion by Drs Merke and Lambertz is extremely well done. More than 500 experiments or experimental results are considered and in many cases illustrated.

The work as a whole is well got up, though the historical portion suffers from a lamentably insufficient index or even table of contents. It can be confidently recommended as a valuable reference book particularly to those concerned in the teaching of physics, though it should be of interest to all workers in physics.

H. B.

Handbuch der Physik. Edited by H. GEIGER and K. SCHEEL. Band IX: Theorien der Warme. Edited by F. HENNING. Pp. 616. Julius Springer (Berlin). Price Reichsmark 49.20.

This volume of the *Handbuch* is the first of the three devoted to the subject of heat. The principles of thermodynamics, the statistical and molecular theory of heat, and the kinetic theory of gases and liquids form the bulk of the subject matter, but chapters on the transformation of other energy forms into heat and on temperature measurement are included.

In Chapter I (Classical Thermodynamics, K. F. Herzfeld) a good general account is given of the mass of thermodynamical results which follow from the First and Second Laws. A brief discussion on the introduction of the variables of state, with which the chapter opens, makes interesting reading. Appeal is made to seven experimental laws before a formulation of the notion of temperature is obtained, a healthy reminder of the complexity of this concept. Curiously enough the Second Law is dealt with without mention of Thomson or Clausius. The author confines himself to Planck's statement of the Law and the other forms are not even quoted. The Nernst Heat Theorem (Chapter II, K. Bennewitz) is developed along historical lines and the attempts to evaluate the "affinity" of a chemical reaction which prepared the way for Nernst's generalization

are fully described. A commendable feature of the treatment is the lucid account given of the extent to which milder assumptions, such as the unattainability of the absolute zero, are equivalent to Nernst's Theorem. Those physicists who appreciate a strict deductive development of thermodynamics employing the minimum number of axioms will find Chapter IV (Axiomatic Basis of Thermodynamics after Carathéodory) particularly interesting. Whether or not Carathéodory's Principle will oust the more usual formulations of the Second Law is doubtful, but the additional elegance of treatment to which it leads amply justifies the inclusion of an account of it in the present work.

Chapter III (Statistical and Molecular Theory of Heat, A. Smekal) deals with a subject on which a considerable amount of work has been carried out recently. The account given starts from first principles and is comprehensive if a little compressed in parts. A valuable feature is the frequent comparison of the forms of distribution laws as given by classical and quantum statistics respectively. A dozen pages are devoted to a consideration of the statistical theories of temperature radiation.

In Chapter VI (Kinetic Theory of Gases and Liquids, G. Jäger) the usual ground is covered with thoroughness and due space is given to the more recent work. A good account is given of density fluctuations in gases and of Smoluchowski's investigation on the opalescence of gases in the critical state. Sections are included on the heat conduction, flow through tubes, etc., of highly attenuated gases.

An excellent discussion of the theoretical bases of temperature measurement is to be found in the last chapter (Temperature Measurement, F. Henning). The optical pyrometer receives very detailed description. In this connexion it is rather surprising to find only one reference to the work of the Nela Laboratory. Similarly in the section dealing with platinum resistance thermometry only two references are made to Callendar's work.

The work as a whole is excellently written and can be recommended without reserve. A certain amount of repetition is unavoidable in a book the several chapters of which come from different hands, but such repetition where it occurs is not without value as each author adopts a slightly different standpoint. It may be added that the printing and general production of the volume attain a high standard.

W. S. S.

TABULAR INFORMATION ON SCIENTIFIC INSTRUMENTS

XVII. DYNAMOMETER VOLTMETERS, AMMETERS, AND WATTMETERS

THE seventeenth of these tables is devoted to electrodynamometer instruments and gives particulars of voltmeters, ammeters, and wattmeters of this type, as furnished by their respective manufacturers. A separate copy of this table may be obtained by any subscriber on application to the Secretary of the Institute of Physics, 1 Lowther Gardens, Exhibition Road, London, S.W. 7, and bound copies of the twelve tables which appeared in Vol. III can be obtained from the same source, price 3*s*. 6*d*. post free.

XVII. DYNAMOMETER VOLTMETERS, AMMETERS, AND WATTMETERS

A. Voltmeters

Type	Cat. No.	Range (volts)	Resistance (ohms)	Inductance (milli-henrys)	Accuracy (%)	Special features or remarks	List Price £ s. d.
Maker:—CAMBRIDGE INSTRUMENT Co., Ltd., 45 Grosvenor Place, S.W. 1.							
Irwin astatic portable	—	Ranges from 3 to 600	15 to 20,000	—	B.E.S.A. sub-standard instruments	Highly astatic	17 0 0 to 20 0 0
Irwin reflecting multi-range	—	2·5, 10, 25, 50, 125, 250 and 500	50 per volt on first 5 ranges	—	B.E.S.A. sub-standard instruments	Supplied with series resistance box	
Unipivot (single range)	—	Ranges from 1·2 to 600	30 to 30,000	—	B.E.S.A. grade 1 instruments	0·04 or 0·02 amp. for full scale deflection. Negligible temperature and no frequency error up to 350	17 0 0 to 18 0 0
Unipivot (multi-range)	—	1·2, 6, 60, 120 and 300	25 per volt	—	B.E.S.A. grade 1 instruments	Fitted with safety switches	22 0 0
	—	6, 60, 120, 300 and 600	50 per volt				
Maker:—ELLIOTT BROTHERS (London), Ltd., Century Works, Lewisham, S.E. 13, *also* SIEMENS BROTHERS & Co., Ltd., Woolwich, S.E. 18.							
Laboratory standard	—	75–750	15 w. per volt	25	0·1	Scale length 12″	91 0 0
S.P.P.	—	„	20 w. per volt	95	0·25	Portable standard. 5½″ scale	27 6 0
P.P.	—	„	20 w. per volt	95	Substandard	Portable standard. 5½″ scale	18 4 0
M.M.	—	„	16 w. per volt	95	1st grade	Industrial, Port. 4″ scale	13 1 6
A.A.	—	„	16 w. per volt	95	„	6″ round, switchboard, 4½″ scale	11 3 3
B.B.	—	„	16 w. per volt	95	„	8″ round, switchboard, 6½″ scale	11 3 3
G.G.	—	„	17 w. per volt	95	„	Sector, switchboard, 12″ scale	16 15 8
C.C.	—	„	12·5 w. per volt	95	„	10″ round, switchboard, 8″ scale	15 0 3
D.D.	—	„	16 w. per volt	95	„	6½″ edgewise, switchboard, 6½″ scale	14 7 3

Laboratory and Portable Instruments have knife-edge pointers, mirror scales, and are specially shielded and damped.
Industrial Pattern Instruments have knife-edge pointers, are shielded, and can be provided with mirror scales.
Other types are made.

Type	Cat. No.	Range (volts)	Resistance (ohms)	Inductance (milli-henrys)	Accuracy (%)	Special features or remarks	List Price £ s. d.
Maker:—Messrs NALDER Bros. & THOMPSON, Ltd., 97 *a* Dalston Lane, E. 8.							
Portable sub-standard and portable industrial	— —	Any range between 0–1000 volts	According to range	According to range	As B.E.S.A. substandard on A.C. and D.C. or B.E.S.A. 1st grade A.C. and D.C. as required	These voltmeters are supplied in single or multi-ranges as required	Varies according to range, etc.
Maker:—THE STONEBRIDGE ELECTRICAL Co., Ltd., Victoria Road, North Acton, W. 3.							
DTLv	61001–5	0–150–300–600	3800 at 150 v.	500	± ·2 full scale	Practically independent of temperature variations or duration of connexion to circuit. Contained in portable oak case, size 250 × 220 × 156 mm., with detachable lid. External zero adjustment. Knife-edged pointer and mirrored scale air damping. Independent of frequency or wave form.	19 16 0
						Series resistances for above can be supplied to extend the range up to 3000 volts	Price 8 10 0 to 14 15 0 extra
						Portable precision multi-range transformers can be supplied up to 15,000 volts.	
DTLsv	60090–2	2, 7·5 or 15	7500 at 150 v.	30	± ·2 full scale	As above, but with ribbon suspension fitted with spirit level and levelling screws. Size of case 250 × 220 × 200 mm.	25 16 0
DTLkv	61131–34	0–15 up to 150 volts	—	—	± ·5 full scale	In portable oak case, size 136 × 120 × 90 mm. Knife-edged pointer practically independent of temperature variations.	From 8 14 0
						External resistance up to 600 volts	5 2 0 extra
Maker:—H. TINSLEY, Ltd., Werndee Hall, South Norwood, S.E.							
Deflecting mirror	—	0–8 m/v.	500	32	·2	Four-range instrument	30 0 0
Torsion head	—	0–4 for 360° restoring movement (500 divisions)	80	40	·05	Transfer instrument, for A.C. and D.C. up to 1000 cycles, also for potentiometer use	27 10 0

Type	Cat. No.	Range (volts)	Resistance (ohms)	Inductance (milli-henrys)	Accuracy (%)	Special features or remarks	LIST PRICE
Maker:—THE WESTON ELECTRICAL INSTRUMENT Co., 15 GREAT SAFFRON HILL, E.C.							£ s. d.
Laboratory standard with knife-edge pointer and mirror scale (12″)	326	Standard range 300/150/75	300 v. = 7200 approx.	0·065 H.	0·1 for D.C. circuits or A.C. circuits up to 133 cycles per second	These instruments are effectively shielded and are supplied for circuits up to 600 cycles per second. They form excellent transfer instruments from D.C. to A.C.	80 0 0
Standard portable testing knife-edge pointers and mirror scales	341	Supplied in any range from 1 volt upwards	Res. varies with range, 750 v. range = 25,000 ohms	0·06 H.	0·25 for D.C. circuits or A.C. circuits to 133 cycles per second	Instruments are effectively shielded and may be checked against D.C. potentiometer. Also supplied for 600 cycle service	32 0 0

B. Ammeters

Type	Cat. No.	Range (amps)	Resistance (ohms)	Accuracy (%)	Frequency variation	Special features or remarks	LIST PRICE
Maker:—CAMBRIDGE INSTRUMENT COMPANY, LTD., 45 GROSVENOR PLACE, S.W. 1.							£ s. d.
Irwin astatic portable (two-range)	—	Six patterns from 0·03 and 0·06 to 10 and 20	170 to 0·15	B.E.S.A. substandard instruments	Negligible at commercial frequencies	Highly astatic, negligible temperature error	18 0 0
Irwin reflecting	—	1	0·15	B.E.S.A. substandard instruments	Ditto	Shunts supplied to extend range up to 500 amperes	20 0 0
Irwin reflecting milliammeter	—	1 or 10 milliamps	600 or 7·5	Ditto	Ditto	—	24 0 0
Unipivot (single range)	—	Ranges from 0·12 to 50	7 to 0·0035	B.E.S.A. grade 1 instruments	Ditto	—	16 0 0
Unipivot (three-range)	—	Any three standard ranges	—	B.E.S.A. grade 1 instruments	Ditto	—	20 0 0
Unipivot milliammeter	—	Four ranges from 0·01 to 0·06	143 to 11·3	B.E.S.A. grade 1 instruments	Ditto	—	16 10 0
Maker:—ELLIOTT BROTHERS (LONDON), LTD., CENTURY WORKS, LEWISHAM, S.E. 13, *also* SIEMENS BROTHERS & Co., LTD., WOOLWICH, S.E. 18.							
Laboratory standard	—	Double range up to 10 amps	0·5 ohm for 5 amp. winding	0·1 max. scale reading	Less than ½ % D.C. to 500 ~	Double range such as: 1 & 2, 2 & 5, 5 & 10	89 0 0
S.P.P.	—	Ditto	Ditto	0·25 ditto	Ditto	Ditto	27 12 6
P.P.	—	Up to 50 amps	0·2 w. for 5 amp. winding	Substandard	½ % from D.C. to 200 ~	Portable. 5½″ scale	18 5 3
M.M.	—	Up to 50 amps	0·32 w. for 5 amp. winding	1st grade	½ % from D.C. to 100 ~	Industrial. Portable. 4″ scale.	13 2 8
A.A.	—	5	0·32 w. for 5 amp. winding	1st grade	½ % from D.C. to 100 ~	6″ round. Switchboard. 4½″ scale	9 12 3
B.B.	—	5	0·32 w. for 5 amp. winding	1st grade	½ % from D.C. to 100 ~	8″ round. Switchboard. 6½″ scale	9 12 3
G.G.	—	5	0·4 w. for 5 amp. winding	1st grade	½ % from D.C. to 100 ~	12″ scale. Sector. Switchboard	13 19 0
C.C.	—	5	0·4 w. for 5 amp. winding	1st grade	½ % from D.C. to 100 ~	10″ round. Switchboard. 8″ scale	12 3 8
D.D.	—	5	0·25 w. for 5 amp. winding	1st grade	½ % from D.C. to 100 ~	6½″ scale. Edgewise. Switchboard	11 10 9

Laboratory and Portable Standard Instruments have knife-edge pointers, mirror scales, and are specially shielded and damped.
Industrial Pattern Instruments have knife-edge pointers, are shielded and can be provided with mirror scale.
Other types are made.

Type	Cat. No.	Range (amps)	Resistance (ohms)	Accuracy (%)	Frequency variation	Special features or remarks	LIST PRICE
Maker:—NALDER BROTHERS & THOMPSON, LTD., 97 *a* DALSTON LANE, E. 8.							
Portable substandard and portable industrial	—	Any range between 0–100 milliamps, or 0–50 amps (or more by means of current transformers)	According to range	As B.E.S.A. substandard on A.C. and D.C. or B.E.S.A. 1st grade A.C. and D.C.	As B.E.S.A.	These ammeters are supplied in single or multi-ranges	Varies according to range
Maker:—STONEBRIDGE ELECTRICAL Co., LTD., VICTORIA ROAD, NORTH ACTON, W 3.							
DTLa	61031–46	0·03 to 100	·03 = 1000, 100 = ·02	± ·2 full scale	Independent	Practically independent of temperature variations or duration of connection to circuit. Contained in portable oak case, size 250 × 220 × 150 mm., with detachable lid. External zero adjustment. Knife-edged pointer and mirrored scale air damping. Independent of frequency or wave form	15 10 0 to 20 14 0
DTLsa	60093–95	·025 to ·1	·025 = 100, ·1 = 8	± ·2 full scale	Independent	As above, but with ribbon suspension fitted with spirit level and levelling screws. Size of case 250 × 220 × 200 mm. Above ·025 amps two ranges can be provided: change made by means of plugs. Multi-range transformers can be supplied suitable for pressures up to 16,000 volts. Ratio error less than ·5 %	22 6 0 to 24 18 0

TABULAR INFORMATION ON SCIENTIFIC INSTRUMENTS

Type	Cat. No.	Range (amps)	Resistance (ohms)	Accuracy (%)	Frequency variation	Special features or remarks	LIST PRICE
Maker:—STONEBRIDGE ELECTRICAL Co., Ltd., Victoria Road, North Acton, W. 3.							£ s. d.
DTLka	61141–43	2·5 to 12·5	—	± ·5 full scale	Independent	In portable oak case, size 136 × 120 × 90 mm. Knife-edged pointer practically independent of temperature variations	From 8 16 0
Maker:—H TINSLEY, Ltd., Werndee Hall, South Norwood, S.E.							
Torsion head	—	0–·05 for 360° restoring movement (500 divisions)	80	·05	0–1000 pps. none	Transfer instrument A.C. to D.C. and for potentiometer use	27 10 0
Maker:—THE WESTON ELECTRICAL INSTRUMENT Co., 15 Great Saffron Hill, E.C.							
Laboratory standard with knife-edge pointer and mirror scale (12″)	326	All double range 1 and 2, 2·5 and 5, 5 and 10	10 A. = 0·2	0·1 for D.C. circuits or A.C. circuits up to 133 cycles per second or 600 if desired	—	Effectively shielded and form excellent transfer instruments from D.C. to A.C.	80 0 0
Standard portable testing with knife-edge pointer and mirror scale	370	All double range, from 0·5 up to 10	10 A. = 0·072	¼ for D.C. or A.C. circuits to 133 cycles	Can be supplied for 1000 cycle circuits with ¼ % guarantee	Effectively shielded and damped	39 0 0

C. Wattmeters

Type	Cat. No.	Ranges (volts, amperes)	Resistances	Inductance of moving coil (millihenrys)	Special features or remarks	LIST PRICE
Maker:—CAMBRIDGE INSTRUMENT COMPANY, Ltd., 45 Grosvenor Place, S.W. 1.						£ s. d.
Irwin astatic portable (three-range)	—	375, 750 and 1500 750, 1500 and 3000 1500, 3000 and 6000	66·67 ohms per volt	3·5	B.E.S.A. substandard accuracy. Complete astaticism. Temperature error negligible	18 0 0 to 19 0 0
Irwin astatic reflecting	—	20, 100, 500, 1000, 2500 or 5000	100 ohms per volt	0·3	B.E.S.A. substandard accuracy. Can be adjusted to give full scale deflection on power factors of 0·1 and less	20 0 0 to 23 0 0
Duddell-Mather	—	0·01 and 0·1, 0·05 and 0·5, 0·1 and 1, 0·5 and 5, 1 and 10, 5 and 50, 10 and 100	100 ohms per volt	5·6	Complete astaticism; large overload capacity, accuracy 0·1 % down to zero power factor Insulated for pressures to 600 v. ,, ,, 12,000 v. ,, ,, 30,000 v. ,, ,, 75,000 v.	 82 0 0 to 150 0 0 95 0 0 to 290 0 0 From 124 0 0 From 143 0 0
Unipivot (single range)	—	Ranges from 0·8 to 1250	300–600 ohms per volt	0·4	Accuracy B.E.S.A. Grade 1. For pressures up to 120 volts	18 0 0 to 25 0 0
Unipivot (multi-range)	—	0·1–400 in six ranges; 1 watt–20 K.V.A. in eight ranges; 10 watts–250 K.V.A. in eight ranges	100–500 ohms per volt	0·4	Accuracy B.E.S.A. Grade 1 6 amp. max. 600 volts max. 60 ,, ,, 600 ,, ,,	30 0 0 to 32 0 0
Maker:—ELLIOTT BROTHERS (London), Ltd., Century Works, Lewisham, S.E. 13, *also* SIEMENS BROTHERS & Co., Ltd., Woolwich, S.E. 18.						
Laboratory standard	—	Up to 750 V. ,, 10 A.	25 ohms per volt	3	Double range of current and volts. Compensated for temperature, power factor and periodicity. Accuracy 0·1 % max. scale	95 10 0
S.P.P	—	,, 750 V. ,, 10 A.	25 ohms per volt	3	Accuracy 0·1 % max. scale Accuracy 0·25 % max. scale	 32 19 6
P.P.	—	,, 750 V. ,, 100 A.	50 ohms per volt	6·2	Substandard Portable	20 17 2
M.M.	—	,, 750 V. ,, 100 A.	40 ohms per volt	6·2	Industrial, portable. 1st grade accuracy. 4″ scale	15 14 8
A.A.	—	,, 750 V. ,, 10 A.	80 ohms per volt	6·2	6″ round, switchboard. 4½″ scale. 1st grade accuracy	11 18 0
B.B.	—	,, 750 V. ,, 100 A.	80 ohms per volt	6·2	8″ round, switchboard. 6½″ scale. 1st grade accuracy	11 18 0
G.G.	—	,, 750 V. ,, 10 A.	80 ohms per volt	6·2	12″ scale, sector, switchboard, 1st grade accuracy	17 10 6
C.C.	—	,, 750 V. ,, 100 A.	80 ohms per volt	6·2	10″ round, switchboard. 8″ scale. 1st grade accuracy	15 15 0
D.D.	—	,, 750 V. ,, 10 A.	80 ohms per volt	6·2	6½″ scale. Edgewise. Switchboard. 1st grade accuracy	15 2 0
S.B.U.	—	,, 750 V. ,, 10 A.	50 ohms per volt	6·2	8″ dial, 5¾″ scale. Polyphase. Switchboard. 1st grade accuracy	23 15 8
D.U.	—	,, 750 V. ,, 10 A.	50 ohms per volt	6·2	6½″ scale. Edgewise. Switchboard. Polyphase. 1st grade accuracy	30 3 8
G.U.	—	,, 750 V. ,, 10 A.	50 ohms per volt	6·2	12″ scale. Sector. Switchboard. Polyphase. 1st grade accuracy	33 18 0
P.U.	—	,, 750 V. ,, 50 A.	50 ohms per volt	6·2	5¾″ scale. Portable. Polyphase. Substandard accuracy	31 7 8
R.U.	—	,, 750 V. ,, 10 A.	15 ohms per volt	6·2	3″ chart, graphic. Polyphase. Switchboard	53 5 6
R.R.	—	,, 750 V. ,, 20 A.	16 ohms per volt	6·2	3″ chart, graphic. Single phase. Switchboard	33 0 8

Laboratory and Portable Instruments have knife-edge pointers, mirror scales, and are specially shielded and damped.
Industrial Pattern Instruments have knife-edge pointers, are shielded, and can be provided with mirror scales.
Other types are made.

Portable Dynamometer Wattmeters

Type	Cat. No.	Ranges (volts, amperes)	Resistances	Inductance of moving coil (millihenrys)	Special features or remarks	List price
Maker:—Messrs EVERETT EDGCUMBE & Co., Ltd., Colindale Works, Hendon, N.W. 9.						£ s. d.
H.P. and H.P.S.	—	Any single current range from 1 to 100 amperes, at any voltage up to 750 volts. Any double range from 1 and 2, up to 50 and 100 amps, by series parallel connection. Any triple range from 0·5, 1 and 2 up to 25, 50 and 100 amps, by series parallel connexion	Power consumption in main coils 4 watts. Current in moving coil varies slightly with the volt range, but is about 0·02 amp.	Varies slightly with the range but is about 0·03 henrys	Made in two patterns, H.P. for general testing work and H.P.S. for standardizing purposes	Varies according to range and type

Wattmeters

Type	Cat. No.	Ranges (volts, amperes)	Resistances	Inductance of moving coil (millihenrys)	Special features or remarks	List price
Maker:—NALDER Bros. & THOMPSON, Ltd., 97 *a* Dalston Lane, E. 8.						
Portable sub-standard or portable industrial, also switchboard pattern	—	Any range between 0–750 V., 0–200 A. (or more by means of current and potential transformers)	According to range	According to range	These wattmeters are supplied in single or multi-ranges as required. For polyphase measurement two elements are employed	Varies according to range, etc.
Maker:—STONEBRIDGE ELECTRICAL Co., Ltd., Victoria Road, North Acton, W. 3.						
DTLw	61051–7	·5–100 amps up to 600 volts internal	5000 ohms at 150 volts	3·4	Practically independent of temperature variations or duration of connexion to circuit. Contained in portable oak case, size 250 × 220 × 150 mm., with detachable lid. External zero adjustment. Knife-edged pointer and mirrored scale air damping. Independent of frequency or wave form. Accuracy ± ·15 % full scale. Current ranges changed by means of plugs. Volt ranges change effected by terminals up to three ranges. Above this up to seven ranges change is made by rotary switch	16 10 0 to 19 5 0
DTLww	61111–7	·5–100 amps up to 600 volts internal	5000 ohms at 150 volts	—	Double element wattmeter for three-phase unbalanced load	51 6 0 to 56 15 0
DTLsw	61101–3	·025–5 amps 150 volts	—	—	Ribbon suspended	24 6 0 to 25 10 0
DTLkw	61151–6	·5–25 amps 600 volts	3500 ohms at 150 volts	1	—	10 10 0 to 29 0 0
DTw	59311–9	·5–200 amps 150–600 volts	—	—	Portable commercial pattern. ± 1 % full scale	13 10 0 to 22 10 0
Maker:—H. TINSLEY, Ltd., Werndee Hall, South Norwood, S.E.						
			Current (ohms) — Pressure (ohms)			
Torsion head	—	2 — 1	3·1 — 100	1·75	Dr Drysdale's wattmeters. Single or polyphase	Single phase
		2 — 5	·1 — 100	1·75		
		2 — 10	·027 — 100	1·75	4 current ranges on each instrument	41 0 0
		2 — 50	·002 — 100	1·75		to 90 0 0
		2 — 100	·0008 — 100	1·75	Ditto	Polyphase
		2 — 200	·0005 — 100	1·75	Ditto	60 0 0
		2 — 250	·0003 — 100	1·75	Ditto	to 135 0 0
		1000 — 250	·0003 — 50,000	1·75	With resistance in pressure system	
		0·5 — 0·05	70 — 10	·6		
Deflecting mirror	—	·7 — 10	·01 — 68	·188	For low power factor measurements	
		·8 — ·2	4 — 40	·192	4 current ranges	
Maker:—THE WESTON ELECTRICAL INSTRUMENT Co., 15 Great Saffron Hill, E.C.						
Lab. std. with knife-edge pointer and mirror scale (12″) single-phase and D.C.	326	300 V. 1 and 2 A., 150 V. 75 V., up to 10 and 20 A.	150 V. = 3500 app.	Compensated. Inductance of potential circuit zero	Guaranteed accuracy of 1/10 % for D.C. or A.C. circuits to 133 cycles and 600 cycles if desired. Very valuable transfer instruments from D.C. to A.C. All have double current ranges and three pressure ranges and current coils will carry 100 % overload continuously	100 0 0
Std. portable testing single-phase and D.C. knife-edge pointer and mirror scale	310	All have two pressure and two current ranges from 0·5 to 1 A. to 50 and 100 A. and pressure ranges from 50 and 100 to 750 and 300	150 V. range	0·0034 H.	Guaranteed accuracy of ¼ % for D.C. or A.C. to 133 cycles and up to 1200 cycles unity power factor. Current coils will withstand 100 % overload continuously and pressure coils 50 % overload	37 0 0
Std. portable testing three-phase, single-phase and D.C.	329	Double current ranges from 1 and 2 A. up to 10 and 20 A. and double pressure ranges up to 750 and 300 V.	150 V. range	0·0034 H.	Guaranteed accuracy of ½ % for D.C. single-phase and three-phase work. Effectively shielded and has evenly divided scale and current coils will stand continuously 100 % overload and pressure coils 50 % overload	60 0 0
Portable testing single-phase and D.C. knife-edge pointer and mirror scale	432	Single current range from 1 A. to 50 A. and two pressure ranges up to 300 and 150 V. self-contained	150 V. = 11,000 app.	0·0056 H.	Effectively shielded and damped, accurate for D.C. or A.C. to 133 cycles. Current coils will stand continuously 50 % overload	21 0 0
Switchboard single-phase and D.C.	167	Single current ranges from 1 A. to 100 A. and any pressure ranges	150 V. = 5200 app.	—	165 mm. scale length	
Ditto	343	Ditto	—	—	130 mm. scale length	
Ditto	427	Single current ranges up to 20 A. and pressure ranges to 250 V. self-contained	—	—	Scale length 63·5 mm.	
Ditto	498	Single current range of 5 A.	—	—	For ranges above 5 A. current transformers are used. Rectangular instruments with bold scale and small external dimensions. Also made as a polyphase instrument	
Switchboard three-phase, single-phase or D.C.	216	Single current ranges to 100 A. and pressure ranges to 300 V. self-contained	150 V. = 6100 app.			

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SECOND LECTURE (JANUARY 5TH) AT THE ANNUAL EXHIBITION OF THE PHYSICAL AND OPTICAL SOCIETIES.

PROGRESS IN THE DESIGN AND CONSTRUCTION OF ELECTRICAL INSTRUMENTS. BY DR C. V. DRYSDALE.

SCIENTIFIC measuring instruments are becoming of ever increasing importance both for research and technical purposes, and it is not too much to say that progress in most directions depends greatly upon the development of reliable and inexpensive measuring instruments. The importance which scientific workers attach to this is indicated by this exhibition and the great interest which is taken in it; and the organizers have laid greater stress upon it by arranging that one of the three lectures should be devoted to the subject of instrument design. The first such lecture was delivered last year by Prof. A. F. Pollard, who dealt mainly with the principles and examples of mechanical design, which applied more particularly to optical instruments; and in view of the great importance of electrical instruments I have thought it well to deal with them. Unfortunately, owing to the large scope of such instruments, it is difficult to deal with them in a connected logical fashion, and my remarks will therefore perforce have to be somewhat of a discursive character and deal with various points which appear to me worthy of attention, particularly as regards what may be called the more homely instruments in general use.

Before entering on these points, however, it seems fitting to pause for a moment to pay a tribute to the memory of three great pioneers of accurate electrical measurements and instruments—Lord Kelvin, and Professors Ayrton and Perry. Those who have made a study of the early work in this direction can only be amazed at the prescience shown by these great pioneers, who nearly half a century ago initiated the great bulk of the measuring instruments we use up to this day, and laid down the fundamental principles which have guided us in their design. To Lord Kelvin, we owe the inception of the sensitive moving-magnet and moving coil-galvanometers, the two principal forms of electrometers, and the first standard dynamometer instruments; while it is difficult to find any important type of electrical measuring instrument which was not initiated or greatly improved by Professors Ayrton and Perry, with the valuable help of Professor Mather.

There are a few general matters to which it may be useful to call attention at the outset. My own experience now goes back about 35 years, and during that time, although enormous improvements have certainly taken place in many types of instruments, there still appear to be some conventions in electrical instrument design which have persisted without change, although it seems difficult to find a justification for them on either electrical, mechanical or commercial principles. Large sheets of polished ebonite with a glittering array of lacquered brass blocks and terminals and fixed on mahogany cases look most attractive in exhibitions, but seem to violate almost every canon of sound electrical and engineering

construction. Thirty years ago the same features were prevalent in indicating instruments, but there has been a steady transition towards serviceable cast metal cases, and mechanical design of the movements and supports; and it is to be hoped that the great development which has taken place during the last few years will cause similar developments in what have been regarded as purely laboratory instruments.

It may not be out of place here to make a general reference to the question of accuracy. In the early days of indicating instruments, when the difficulties were much greater than they are now, the question of accuracy of electrical measurements and instruments was always a matter of keen interest. Many animated discussions took place on it, and the manufacturers of even the commoner indicating instruments vied with one another to secure the highest possible accuracy then obtainable. In my own commercial experience no soft iron ammeter was passed with a higher error than $\pm$ 1 per cent. of its top reading, and I am definitely of opinion that no instrument of lower accuracy is worth the making, except perhaps small instruments for motor cars etc.

Although instruments may not form a very large portion of the electrical industry, their calibre is liable to be taken as an index of the perfection of all its products; and as an accuracy of within 1 per cent. is easily attainable, no lower standard should be recognized. Unfortunately since the war the great interest which has been taken in high frequency and valve work, while it has enormously increased the scope of electrical measurements, has most certainly detracted from their accuracy, and very little attention is now being given by scientists to the accuracy of ordinary measuring instruments, or to standards. Before the war, discussions and conferences on electrical standards and accurate measurements were of at least annual occurrence, but there has not been one such conference since, and all scientific interest in the matter seems to have died out. I would venture to suggest that the time has come for a revival of attention to this subject, and that it would be a valuable impetus to the whole electrical industry.

The only other general point to which I feel I must refer is the question of the facilities for the production of instruments. Although British machine tools of the heavy type are remarkably fine productions, their manufacturers seem disinclined to trouble about the light, accurate and versatile machine tools required for instrument making; and whenever one visits a large instrument factory one finds it filled with American and Continental machine tools.

No doubt this is largely due to the failure of this country to take up the mass production of clocks and watches in the last generation, but the number of machine tools required for instrument work when we include such industries as telephone, sound reproducing and railway instrument work is by no means unimportant, and it would certainly be a great advantage all round if good small lathes, milling machines, grinding machines, and gear cutters were obtainable in this country at a reasonable cost.

Materials. Electrical instruments, perhaps more than any other devices, are very greatly dependent upon the properties of materials, and since the war there have been a few very marked advances which are already beginning to have an important effect and which may lead to great future developments. Perhaps the most important of these improvements is in the direction of magnetic materials. Until recently permanent magnets though a very important feature of many measuring instruments, were somewhat troublesome, owing to their low coercive force, which rendered them liable to self-demagnetization and required a careful artificial ageing process in order to secure reasonable permanence. With the advent, however, of the modern Cobalt and Cobalt-Chrome magnet steels, the coercive force has been increased from the 50 to 60 gausses of tungsten steel to something like 200 to 250 gausses; and although this has been obtained with a reduction of magnetic density from about 11,000 to 9000 gausses, it is now possible to obtain much higher and more

permanent densities in the gaps of permanent magnet instruments, and with the use of shorter and more easily built-up magnets. Instrument makers have been somewhat slow to avail themselves of this form of magnet steel; partly no doubt, to the fact that it involves somewhat radical alteration to the design in order to make use of it in the most economical manner; but in view of the valuable results obtained with it in magnetos and other devices, there can be little doubt that it is destined to become more and more largely used for moving coil instruments. For moving magnet galvanometers and other devices requiring short magnets, cobalt steel is of very great importance owing to its freedom from demagnetization, and it should be pointed out that it will take a high degree of polish, so that the magnet itself may be made to serve as a mirror and avoid the extra inertia of a separate silvered mirror.

As regards high permeability materials, on the other hand, a startling advance has been made by the introduction of a class of nickel irons introduced under the title of Permalloy by the Weston Electrical Co., Ltd., in America and in a nearly similar form as "Mumetal" by the Gutta Percha Company in this country*. These alloys, which contain about 78 per cent. of nickel, the remainder being iron, with, in some cases, a little copper, have a most extraordinary permeability in weak magnetic fields; the maximum permeability being of the order of 30,000 to 40,000 in a field of about ·1 gauss, so that a long specimen of this material will almost saturate when held in the earth's magnetic field. The hysteresis of these alloys is also extremely low, being something like a fifth to an eighth of the value for the best soft iron, and this, in combination with the very high permeability should make them most valuable for high frequency transformers and also for current transformers for alternating current measuring instruments.

It must be borne in mind however that this material must be annealed with great care, as in its ordinary unannealed form it may be greatly inferior both in permeability and hysteresis to ordinary iron, and to obtain the best effects it must be annealed at a temperature of 900° for a few minutes in an inert gas such as nitrogen, and be subjected to the smallest possible strains either from bending or tooling after annealing if it is to retain its valuable qualities. It seems certain that these alloys will gradually bring about a vast improvement in electromagnetic devices, as their high permeability diminishes the magnetizing force required, and their low hysteresis tends to reduce the holding on or sticking effects which are so often annoying with ordinary electromagnets. An enormously important and useful application however appears to be in the direction of obtaining magnetic screening which is a matter that has often been attempted with ordinary materials but with little success.

In the early part of the present year, I made the suggestion that it should be possible to obtain a very high degree of magnetic screening by using a cover of $\frac{1}{16}$ to $\frac{1}{8}''$ in thickness of Mumetal, and Professor Hill and Mr Downing have carried this suggestion into effect in their valuable recent work on the improvement of moving magnet galvanometers, with the result of finding that it is possible to reduce the field inside a tubular cover of this material to about a thousandth part of the external field and thus to make a very sensitive moving galvanometer almost independent of magnetic disturbances. It would therefore appear that if the makers of various indicating instruments were to inclose their instruments or at least their movements, in thin cases of this material, the troublesome effects of magnetic disturbances due to the proximity of heavy current bus-bars could be practically eliminated.

The enormous advance which these nickel iron alloys have exhibited in the obtaining of high permeability at low inductions has however been unfortunately accompanied by a reduction of the maximum workable induction which is only of the order of 10,000 gausses;

* *Journ. Scient. Insts.* September, 1925.

but the great success achieved in this direction emboldens one to hope that it may not be impossible to achieve similar results at the upper end of the magnetization and greatly increase the maximum magnetization.

Anyone who has had great experience in the designing of electromagnetic mechanisms must sooner or later have realized the very serious limitation which is put upon their effectiveness by the saturation of the iron. A bar of steel of 1″ square section will bear a mechanical load of anything from 30 to 50 tons before breaking, but if this bar is cut and the ends faced off and magnetized as strongly as possible, say to $B = 20,000$, the force required to separate them is only of the order of 100 lbs., so that the ratio of the cohesive to the magnetic force is something of the order of 1000 to 1. When one comes to consider magnetic as compared with mechanical shearing forces the ratio is far greater, and it is for this reason that the ratio of torque to inertia is so extremely poor in electromagnetic motors and other electromagnetic devices in comparison with mechanical mechanisms. Remembering also, that these relatively poor forces or torques can only be continuously maintained by a constant waste of power in heating the coils, the serious defect of electromagnetic mechanisms becomes even more evident; and the great remedy would be an increase of the working induction in the iron, as doubling the induction would produce a four-fold increase of the forces or torques.

Were it not for the convenience and flexibility of electrical connexions it is safe to say that electromagnetic mechanisms would never have had the smallest chance against mechanical, pneumatic, or hydraulic ones; and the effectiveness of small electromagnetic devices can never be great until the saturation value of the magnetic materials can be materially raised.

At the other end of the scale, reference may be made to the first really practical attempt at producing a virtually nonmagnetic workable form of iron by Messrs Ferranti under the title of "Nomag" Iron*. This material, which can be obtained in the form of cast rods or other forms, has a permeability of only about 1 per cent. above unity, but has the enormous advantage over the old forms of almost unworkable manganese steels of being fairly easily turned and screwed, whilst its mechanical strength is high. The applications of this material may not be so numerous for the instrument maker as the alloys above mentioned, but it is worth bearing in mind for several components.

Another very important advance has been in the evolution of synthetic resin products for insulators. The first of such products was discovered as far back as 1872 by Beyer and developed into practical form by Bakeland in 1884, resulting in the group of materials known as Bakelite. The basis of these products was phenol-formaldehyde, $C_{42}H_{22}O_6$, obtained by the action of formaldehyde on carbolic acid, and this compound had a breakdown voltage of 40,000 volts per cm. Combined with various "filling" materials such as wood fibre or asbestos powder it forms a very hard, durable, and highly insulating substance, which can be moulded under heat and pressure into any form, with a high finish, and with metal blocks or other fittings embedded in it. On a recent visit to the United States I found high-grade resistance boxes and other instruments being turned out complete from the presses ready for mounting the coils and screwing on the terminal heads; and this example might well be considered in the manufacture of the more standard forms of apparatus, where the quantity justifies the necessary prime outlay on the hot presses and moulds. Bakelite is certainly greatly superior to ebonite for cost and electrical and mechanical properties, and other synthetic products are coming forward which may still further increase our resources. During last year Prof. Moureau and M. Dufraigne introduced an Aldehyde of Amyl Alcohol under the name of Acrolein Gel or "Orca,"† which has excellent

* *Journ. Scient. Insts.* January, 1926, p. 124.

† *Journ. Scient. Insts.* September, 1925.

insulating and mechanical properties although it is unsuitable for high temperatures; and in his recent lectures Prof. Fleming spoke of a new product, tri-aceto cellulose or "Cellite," $C_6H_7O_2(CH_2CO_2)_3$, which can be dissolved in camphor like celluloid, but is non-inflammable, and has a breakdown voltage of 42 Kilovolts per cm. It can be silvered and used for condensers.

Before closing this section, reference should be made to the advances which have been made during the last few years in the production of light alloys—mainly stimulated by the needs of aircraft. Such alloys are coming into use for aircraft and instruments and are very convenient both for their lightness and adaptability for die-casting, but serious troubles have been experienced with some of them, owing to their unfortunate tendency to deform after completion, and it is doubtful whether any of them are suitable for accurate work. Dr Rosenhain has given a remarkable illustration of this tendency of aluminium-zinc alloys to grow or deform, in the case of a circular label which was screwed to a compressor set. Figs. 1 and 2 have been reproduced from his note on "Some Cases of Failure in 'Aluminium' Alloys" read before the Institute of Metals in March 1922. Alloys of zinc with aluminium are especially dangerous in this respect, but even the copper-aluminium alloys are subject to the trouble, and perhaps the aluminium-silicon alloys such as "Duralumin" or "Alpax" are the best, though the former cannot be cast and is liable to warp seriously in machining.

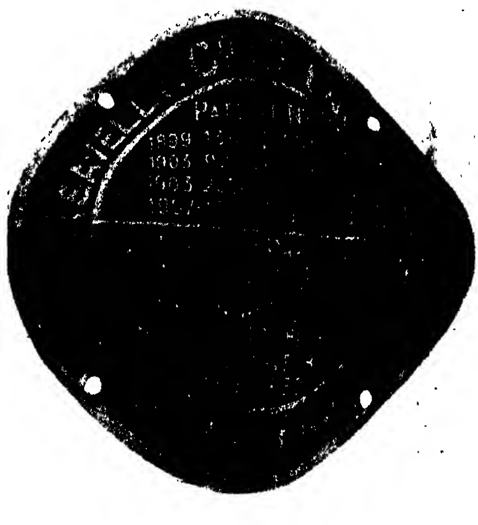


Fig. 1

Fig. 2

Within the last few months a further great advance in lightness has been achieved by the introduction of magnesium, generally alloyed with a little copper, under the name of "electron" metal. It has a specific gravity of only 1·7 and is fairly strong and easily cast or machined, but its permanence of form still needs investigating, and great care should be taken to avoid the possibility of its coming into contact with seawater, which rapidly dissolves it. All light alloys appear to give more or less trouble in this respect, and it is to be hoped that some means may be found for overcoming it. For the present it would appear that although light alloys have their uses, they should only be adopted as a rule for covers and other parts where accuracy is not vital, and even then only when there is practically no risk of corrosion.

We will now turn to the consideration of some of the leading classes of instruments, dealing first with the indicating instruments for P.D., current, and power measurement, and afterwards with instruments for laboratory and research work.

I. Indicating Instruments

Although these instruments do not appear of great interest to the scientific worker who is apt to take them for granted, they are of immense importance both to such workers and to the whole electrical industry; and to those who have been concerned in their production

they still offer most interesting problems and scope for further great improvements. The subject is far too large to permit of more than a general review and brief reference to a few special points, but in view of the multiplicity of types it may be well to indicate what seems to be the likely tendencies for the future.

As regards ammeters and voltmeters for ordinary ranges, both the soft iron and the moving coil type will continue to hold the field, the former on account of its high accuracy, long and even scale, low power consumption and adaptability for shunting or series connexion so as to provide for a large range of current and P.D. measurements; and the latter for its cheap construction and adaptability for both D.C. and A.C. working. Moving-coil permanent-magnet instruments have been brought to such a high degree of perfection by Dr Weston that there is little room for improvement, except perhaps by the introduction of cobalt steel magnets and permalloy cases to ensure good screening from magnetic disturbance; but great credit is also due to Mr J. W. Record for the careful design and excellent construction of his Cirscale instruments, which are among the best examples of purely British indicating instrument construction. The advantages of having a large open scale with an arc of about 270° are obvious for convenience of reading at a distance, but it is doubtful whether such long scales are advisable from the point of view of the highest possible accuracy, since the total flux and therefore the maximum torque cannot easily be increased, so that the periodic time and frictional errors are liable to be larger, and the long thin springs required are more apt to deform or be strained beyond their elastic limit.

As regards moving iron instruments, however, although many of them are now very satisfactory instruments, there yet seems to be a possibility of very great improvement. The great difficulty with practically all alternating current instruments is their limited range owing to the "Square Law," and although soft iron instruments are better in this respect than many others it is rare to find one which has a useful range of more than 5 to 1. As such instruments, at least hitherto, have not been suitable for use with shunts, owing to their inductance, it requires a large number of them to cover the range of from say 1 to 500 amperes or more, and one of the most important problems yet to be solved is the extension of the range of these and other A.C. instruments.

In order to consider how this may be done, reference may be made at this point to an important general principle, which I have found of the greatest value in all instrument design, and may even be employed with advantage in the design of electrical machinery. The majority of electromagnetic instruments and electric motors and generators may be reduced schematically to a coil and a magnet. If the magnet is permanent or separately excited and has N linkages with the coil, then if i is the current in the coil, the electromagnetic potential or energy of the system $e = Ni$, and if a steady current is maintained in the coil, and either it or the magnet moves so as to vary N, this potential energy changes, and the mechanical force F or torque T required to produce this movement is given by $F = i\dfrac{\partial N}{\partial x}$ or $T = i\dfrac{\partial N}{\partial \theta}$, where x is the rectilinear displacement or θ the angular rotation. This formula applies to permanent magnet moving coil instruments or galvanometers, or to moving needle galvanometers.

If, on the other hand, the magnet is excited by the coil, which has an inductance L as in a soft iron instrument, the electromagnetic energy is $\frac{1}{2}Li^2$, and we have correspondingly $F = \frac{1}{2}i^2\dfrac{\partial L}{\partial x}$ or $T = \frac{1}{2}i^2\dfrac{\partial L}{\partial \theta}$. In a dynamometer instrument having two separate circuits as in a wattmeter, carrying two currents i_1 and i_2, then the linkages $N_1 = Mi_2$, and $T = i_1\dfrac{\partial N_1}{\partial \theta} = i_1 i_2\dfrac{\partial M}{\partial \theta}$; but if the two coils are in series as in a dynamometer voltmeter the

total inductance $L = L_1 + L_2 + 2M$ and $\frac{\partial L}{\partial \theta} = 2\frac{\partial M}{\partial \theta}$, so that $T = i_1 i_2 \frac{\partial M}{\partial \theta} = \frac{1}{2}i^2 \frac{\partial L}{\partial \theta}$ as in the soft iron instrument. Finally for electrostatic instruments the electrostatic potential $= \frac{1}{2}KV^2$ so that the torque $T = \frac{1}{2}V^2 \frac{\partial K}{\partial \theta}$. These formulae are summarized in the following table:

Type of Instrument	Torque
Permanent magnet instruments	$i\frac{\partial N}{\partial \theta}$
Soft iron and series dynamometer instruments	$\frac{1}{2}i^2\frac{\partial L}{\partial \theta}$
Dynamometer Wattmeters	$i_1 i_2 \frac{\partial M}{\partial \theta}$
Electrostatic instruments	$\frac{1}{2}V^2\frac{\partial K}{\partial \theta}$

By the aid of these formulae we can easily find the torque of any of these types of instruments without opening them up, but their great importance lies in their guide to design. For example, if we take the soft iron instrument we see at once that its torque depends upon the change of its inductance, and that therefore to obtain the highest possible torque, the total change of inductance between the bottom and top of the scale or $L - L_0$ should be as high as possible. On the other hand, in order to keep inductive errors to a minimum, the total inductance L should be as low as possible. The ratio of useful change of inductance $L - L_0$ to L should therefore be as near unity as possible, and I suggest that it should be called the electromagnetic efficiency of the instrument. When we come to examine existing soft iron instruments, we find that few of them have an electromagnetic efficiency of more than 10 per cent., while in many cases it is only 1 or 2 per cent. or even less; implying that of the total inductance 98 per cent. or more is useless and noxious, and only 2 per cent. useful in causing the deflection. If we take a 5 ampere ammeter and assume that it is to have a simple square law scale, $\frac{\partial L}{\partial \theta}$ should be constant over the whole range, and if the maximum torque for a deflection of say 90° is to be ·2 gram cm. or 200 dyne cm. for the 5 amperes or 0·5 C.G.S. unit, then $\frac{1}{2}i^2 = \cdot 125$ and $\cdot 125\frac{\partial L}{\partial \theta} = 200$, so that $\frac{\partial L}{\partial \theta} = 1600$ C.G.S. units or 1·6 microhenrys per radian. As 90° is about 1·6 radians this means that $L - L_0$ should be 2·56 microhenrys, while if the coil is to absorb 2 watts at 5 amperes, its resistance will be ·08 or 80,000 microhms.

For a 50 ~ supply having a pulsatance $\omega = 314$ and assuming L_0 is zero, the reactance at maximum deflection is $2{\cdot}56 \times 314 = 795$ microhms or only 1 per cent. of the resistance, so that the maximum error when shunted with any non-inductive resistance would be only about 1 per cent. at commercial supply frequencies. But if the electromagnetic efficiency is only 10 per cent. the error when heavily shunted will be ten times as great.

For a voltmeter requiring a maximum current of 0·05 ampere and the same torque the range of inductance $L - L_0$ will be 100^2 times the above or 25·6 millihenrys and the corresponding reactance at 50 ~ would be about 8 ω. The difference between the direct and alternating current indications of a voltmeter $= \frac{1}{200}\left(\frac{x}{r}\right)^2$ per cent., where x is its reactance and r its resistance, so that if this is to be limited to 0·1 per cent., $\left(\frac{x}{r}\right)^2 = \cdot 002$, and $r = 22x = 22 \times 8$ or 176ω, giving a P.D. of about 9 volts for the ·05 ampere working current. With nearly unit electromagnetic efficiency, therefore, a 10 volt soft voltmeter could be produced with negligible inductive error at ordinary supply frequencies; and a

100 volt instrument of the same type would have an error of less than ½ per cent. at all frequencies up to 1000 ~, provided that it was free from eddy currents. These examples amply demonstrate the importance of a high electromagnetic efficiency, and it is to be hoped that manufacturers of indicating instruments will concentrate their attention upon attaining it.

(To be continued)

NOTES UPON THE MECHANICAL DESIGN OF SOME INSTRUMENTS SHOWN AT THE EXHIBITION OF THE PHYSICAL AND OPTICAL SOCIETIES, 1927. By A. F. C. POLLARD, A.R.C.S., A.M.I.E.E., F.Inst.P. Professor of Instrument Design at the Imperial College of Science.

Those who were present at the Annual Exhibition of the Physical and Optical Societies this year could not have failed to note the increase of the variety of scientific instruments in general and the steady improvement of mechanical design in some of the instruments in particular. The slow realization that the application of strict kinematical principles to design will produce a better instrument with attendant economy of manufacture is possibly responsible for this improvement, but it cannot be doubted that the influence of the Cambridge Instrument Company has been very great in this matter. It will repay any designer and indeed all users of scientific instruments to make a close study of this firm's products.

This year the Cambridge Instrument Company did not exhibit any instrument showing particular novelty from the point of view under discussion, and many of the instruments exhibited have been described elsewhere.

The micro-indicator designed by Mr W. G. Collins and shown last year, in which the celluloid disk on which the stylus scribes an indicator diagram of minute dimensions, has been modified in an instrument made for the London and North Eastern Railway and was shown by courtesy of the Chief Mechanical Engineer. In this instrument the disk has been replaced by a continuous length of film 12 millimetres wide on which it is possible to obtain hundreds of successive diagrams in place of the 10 diagrams the disk could accommodate.

This ingenious method of recording the movements of an instrument indicator should have wide applications. Since the line described by the stylus is not a scratch but a minute groove formed on the polished surface of the celluloid by plastic flow, the pressure and sliding resistance between the stylus point and the celluloid is extremely small. The measurement of the record under a microscope is facilitated in a happy way by the groove acting in the manner of a cylindrical lens and revealing itself as a bright line of almost infinitesimal breadth with transmitted illumination. This action of the groove upon transmitted light has been described by Mr Collins in *Transactions of the Optical Society*, **27**, p. 215.

The simple method of quickly applying the thermo-couple of the Surface Pyrometer to a heated curved surface under working conditions is worthy of note. A thermo-couple, consisting of a thin strip of copper and constantan with the junction at its mid-point, is stretched across the ends of an inverted bow spring fixed to the underside of a metal casting and its ends are connected to a millivoltmeter mounted on this casting. The thermo-couple strip is pressed into contact with the heated surface and a reading of the temperature of

a clean surface can be obtained in 3 to 5 seconds. The standard ranges are 0–400° F. or 0–200° C.

Though outside the scope of this article the author cannot refrain from drawing the attention not of physiologists but of physicians in charge of hospital wards to the Glass Electrode Potentiometer embodying the method developed by Mrs P. M. Tookey-Kerridge[1]. It is now possible that most valuable diagnostic data may be collected on the pH value of the blood at the onset of the specific infectious diseases and of the diseases of the blood itself and ductless glands.

In the fine series of optical apparatus exhibited by Messrs Adam Hilger, Ltd., some details of design must now be described.

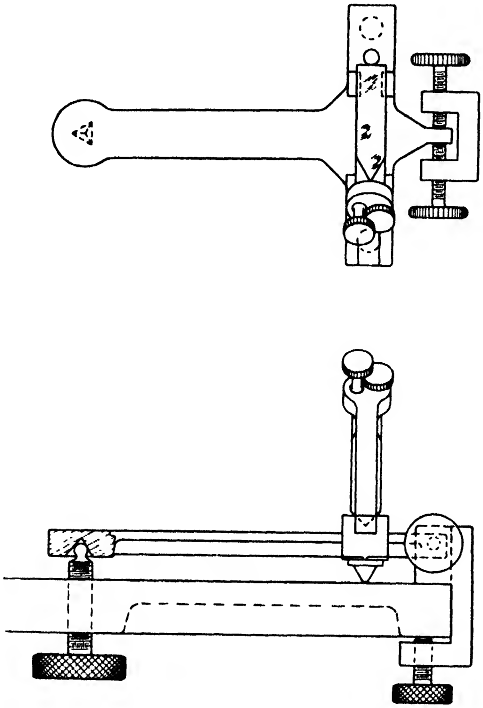


Fig. 1

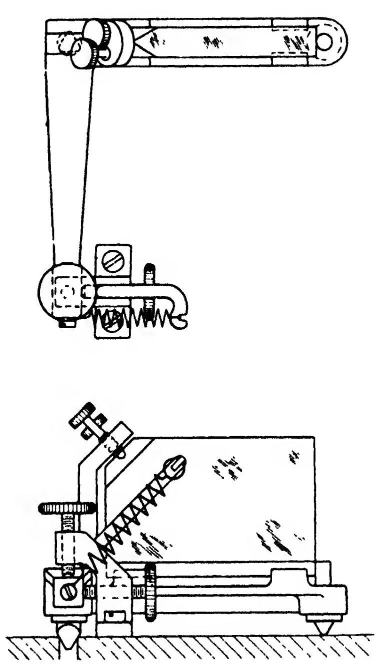


Fig. 2

The Student's Interferometer is a first class example of sound design. Fig 1 shows the method of mounting and adjusting the mirrors and Fig. 2 the method of mounting and adjusting the parallel plate.

In both these figures it will be seen that the glass plates are fixed to their frames in the same way. The plates are bevelled along their lower edges and at 45° to the horizontal across one of the upper corners. The two planes of the lower bevel rest upon the inner edges of four lugs projecting from the frame. This at once limits the movements of the plate to a translation along and a rotation about a line approximately parallel to the lower edge. The ends of two adjusting screws contact on the two planes of the upper corner bevel which limits the rotation and enables the mirror to be tilted until it is nearly square to the frame. At the same time the screws press the vertical side of the plate against a cylindrical stop in line with the lower edge. In this way the plate is completely fixed by six contacting points, four on the edges of the lugs, one on the cylindrical stop and the sixth on one of the upper adjusting screws, the other screw merely producing the necessary pressure against this sixth point.

* *Biochem. Journ.* **19**, 611 (1925).

In Fig. 1 the mirror-carrying frame is a T-shaped piece virtually resting on three feet on the interferometer table. The line joining the contacts of the two feet which actually rest upon the table is immediately below and approximately parallel to the lower edge of the mirror, but the other foot at the far end of the T is actually a trihedral hollow resting upon the spherical end of an adjusting screw paired with the table. Thus by turning this screw the frame and hence the mirror is tilted about an axis which is the join of the contacts of the two feet on the table. The trihedral hollow imposes upon the frame three constraints, i.e. the three possible translations of the frame parallel to the three co-ordinate axes which pass through the centre of the spherical end of the screw. The two feet introducing two more constraints, leaves the frame with the single degree of freedom of rotation about an axis perpendicular to the table through the centre of the spherical end of the adjusting screw. This last movement is constrained by the pressure of the vertical face of a projecting arm against the end of a horizontal adjusting screw, the reaction being taken by a similar and opposing adjusting screw. The mirror is therefore held by a six point constraint in the frame which itself is also fixed relatively to the table by six point constraints, and these constraints have a far more definite action in preventing any possible shake or wobble between the components without unnecessary and fatal elastic strains than any system of studs and bolts.

The preference of the trihedral hollow to a conical hollow should be noted. The trihedral hollow can be constructed by pressing a trihedral punch into the soft brass, and is not more costly to produce than drilling a conical hollow. In fact the punching is to be preferred, for the operation tends to harden the faces of the hollow. But a conical hollow violates the very principles of kinematic design, for should the hollow develop during manufacture a slightly elliptical instead of a circular section, or should a speck of dust or a hair become lodged between the contacting surfaces the spherical end of the screw will only contact at two points with a small rolling motion, and for the same reason the end of the screw must be a true sphere.

With a trihedral hollow there will always be contact at three definite points whether the end of the screw be spherical or not.

In Fig. 2 the frame bearing the plate is L-shaped and constrained in a different way. Of the two feet resting on the table one contacts at three parts of the edge of a hole drilled in the table. These contacts are obtained by machining three flats on the conical surface of the foot, so that the three remaining parts of the cone touch the edge of the hole in the table. This is a simple way of securing the triple point contact with cast iron which cannot be punched. The frame now has two degrees of freedom, i.e. a rotation about a line parallel to the two feet and a rotation about the perpendicular to the table through the centre of the drilled hole. The two rotations are constrained by two adjusting screws acting at right angles to one another and contacting against horizontal and vertical plane surfaces formed on the end of the arm of the L-shaped frame. The reaction against these screws is produced by the spring shown. Thus by rotating these two screws the plate can be rotated in azimuth and about a horizontal axis parallel to its plane.

As in the former fitting the construction is simplicity itself and the variance of the movements is reduced to a minimum.

The New Model Measuring Micrometer, with 6-inch travel reading to one micron, is worthy of careful study by those engaged in the construction of measuring instruments. The bed and slide of the instrument are in one massive casting and the reading microscope is fixed to the bed. The slides are worked to optical accuracy and all the constraints of the coacting parts conform to kinematical principles. As the instrument has been fully described by the designer, Mr J. H. Dowell (who is to be congratulated upon a piece of exceptionally fine design), in the *Proceedings of the Optical Convention*, 1926, no further description is

necessary here. Attention must also be directed to this firm's Interchangeable Spectrographs. These spectrographs are made in three models, differing mainly in the number of their accessories for greater convenience in adjustment, and each model is made in three sizes. Each model consists of a girder base on which is mounted a camera and a focussing carriage with rotating table. The carriage and table is designed to take interchangeably any of the following optical systems:

(*a*) Eagle Mounting Concave Grating.
(*b*) Littrow Mounting with Quartz Prism and Lens.
(*c*) Littrow Mounting with one Glass Prism and Lens.
(*d*) Littrow Mounting with one 30° and one 60° Glass Prism and Achromatic Lens.
(*e*) Littrow Mounting with Plane Grating and Achromatic Lens.

Such interchangeability is very simply secured when the design of the co-acting parts is kinematic, and the main advantage to the user of any one model with one system is that without further cost of special adaptation or of a new instrument any other system may be added later with no possible doubt as to perfection of fit. It is hoped that microscope manufacturers will at some future date proceed on similar lines. If it were possible to purchase a really rigid and carefully designed full length slide representing an optical bench of girder form mounted on a foot and interchangeable fittings, such as an objective saddle, an eyepiece saddle, a stage saddle, a condenser saddle, etc., to which could be attached kinematically, objectives, eyepieces, different forms of stage, condensers, etc., the user could in time build up a valuable research microscope as his pocket permitted. The optical-bench-slide could be similar to, though simpler than, the limb of the fine "Massive" Research Microscope shown by Messrs R. and J. Beck, Ltd.

There would be no need to have a body tube, it would serve no mechanical purpose and it could be more usefully replaced by a black velvet curtain supported on a light wire frame. The slide could have a rack running along its whole length and the fine adjustment should be a separate mechanism which could be clamped to the slide to actuate the objective, condenser or stage as one wished. It is sometimes essential to be able to place subsidiary apparatus in the optical path immediately behind the objective or in front of the eyepiece, and these things cannot be conveniently or quickly done with the present stereotyped design of microscope in its multitudinous forms of bewildering variety.

The New Model (1926) Constant Deviation Wave-length Spectrometer deserves special attention. As will be seen in Fig. 3 the working parts of the instrument as well as the prism are protected and covered with cast aluminium shrouds, and the appearance of the instrument appeals to the aesthetic sense—a not unimportant consideration in design.

In Fig. 4 the details are shown of the focussing mechanism of the O.G. as well as the manner of fixing the eyepiece tube in the main casting. It will be observed that the eyepiece tube required to have axial translation in order that it may be removed, and when in position it must be capable of being fixed without warping out of alignment. The casting is bored out to receive the end of the tube and is split along the top as at *D*, Fig. 3. A clamping screw draws the casting together so as to force the eyepiece tube down upon four screws which bear upon four raised surfaces on the tube. By adjustment of these screws the tube axis can be aligned once for all, and the design is most efficient from every point of view.

The tube carrying the O.G. is supported in a similar manner upon four screws shown as dotted circles; its axial rotation is prevented by the loose engagement of a projecting stud with a slot in the casting.

A bell crank lever bears against the stud and the end of the focussing screw shown at *A*, Fig. 3, and in detail in Fig. 4.

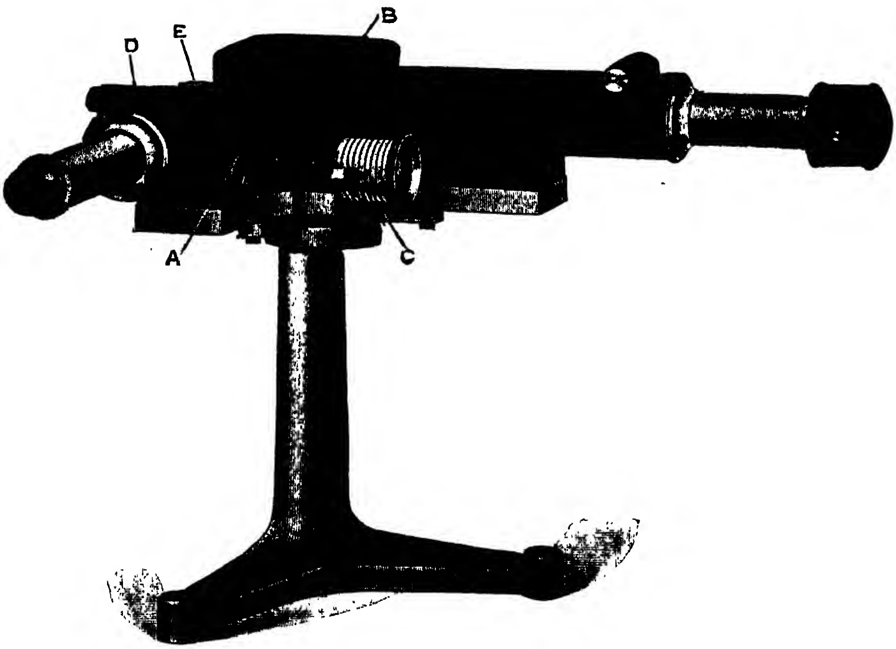


Fig. 3

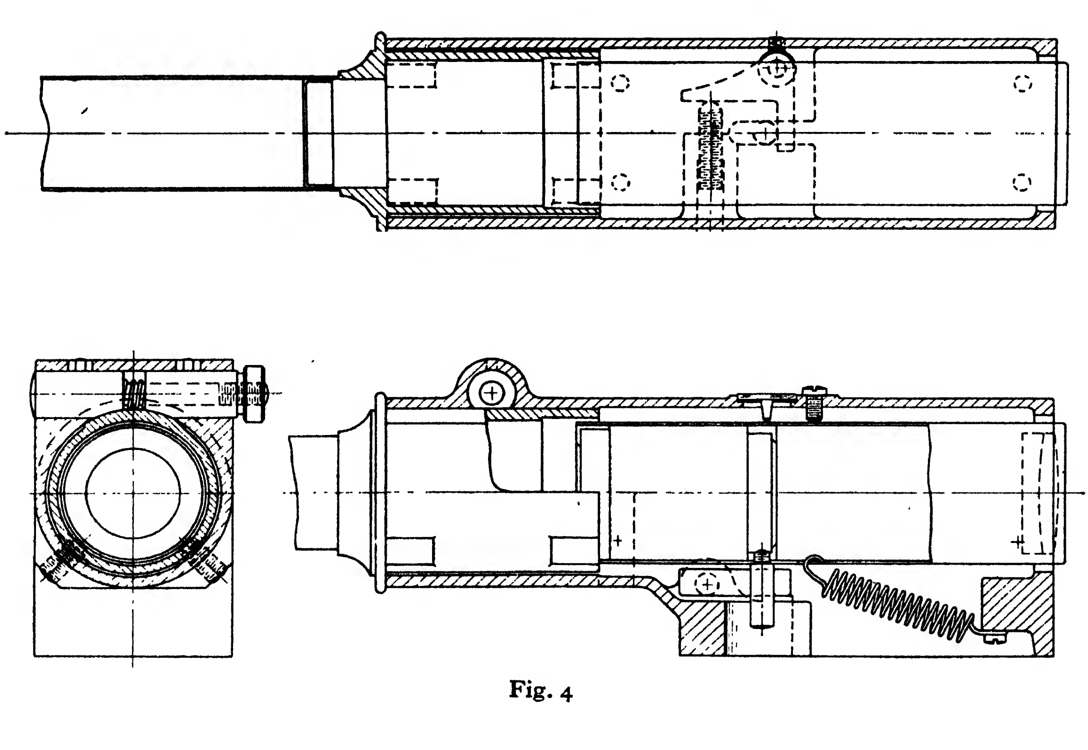


Fig. 4

The spring shown serves the purpose of urging the O.G. tube against the four bearing screw points, the stud against the lever and the lever against the point of the focussing screw. The set screw at the top of the casting immediately over the centre of the O.G. tube does not touch the latter, but prevents too great an accidental displacement of the O.G. tube from off its four bearings. Just beside this set-screw is an opening, *E*, Fig. 3, in the casting closed with a glass plate through which a scale engraved on the O.G. tube can be seen.

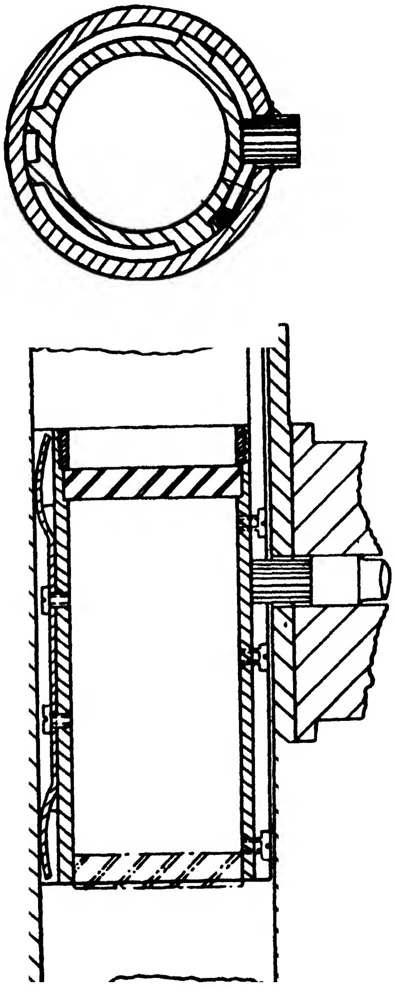


Fig. 5

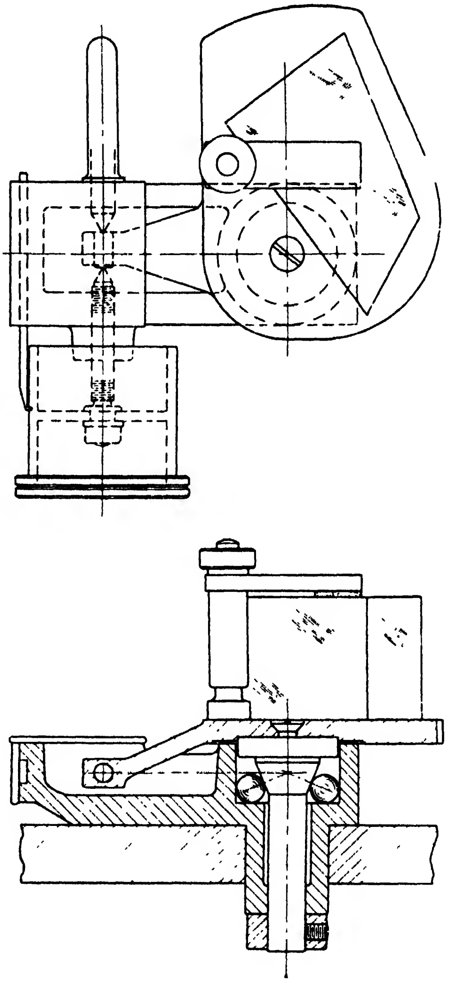


Fig. 6

The O.G. tubes of the Nutting Photometer and the Rayleigh Refractometer for Liquids and Gases are designed in the same way. The complete satisfaction the movement gives in the last named instrument is sufficient testimony to its perfection.

Messrs Cooke, Troughton and Simms, who exhibited a fine series of surveying instruments, have adopted a form of slide for the internal focussing lenses of their telescopes substantially similar to the above. The internal focussing lens must move axially with minimum lateral displacement, and the way this firm achieve this condition is shown in the sectional Fig. 5.

The lens is carried in a tube with four external projections which are made to bear against the inside surface of the body tube of the telescope by the pressure of a flat spring as shown.

Rotation of the tube is prevented by the pressure of the back edge of the rack against a piece fixed to the inside of the telescope tube.

The design of the prism table of the Hilger Spectrometer, shown in Fig. 6, introduces a novel feature in the design of these instruments. The spindle of the prism table is conical at its upper end to form a ball race, and the lower end of the spindle is a functional fit in a bearing.

The fit of the spindle at its lower end with the bearing requires a metal clearance or the spindle would not turn. The spindle must suffer therefore a small shake which may develop with use. This may be unimportant as far as the optical performance of the prism is concerned; but it is essential that the distance of the point of contact of the micrometer screw from the axis of rotation of the prism is constant for any given reading of the wave-length drum. This condition is readily secured by arranging the co-acting parts so that the line perpendicular to the axis passing through the contacting point of the micrometer screw also passes through the common meet of all the normals to the conical surface of the spindle at the ball contacts. It is obvious that this point on the axis is the instantaneous centre of rotation of the prism table.

(*To be continued*)

DESCRIPTIONS OF THE EXHIBITS AT THE EXHIBITION OF THE PHYSICAL AND OPTICAL SOCIETIES

(*Continued from p.* 170)

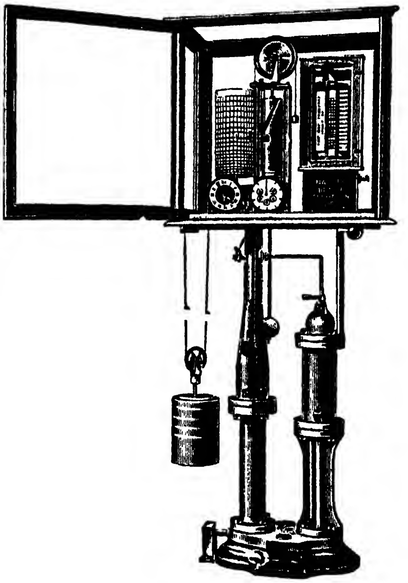
COMMERCIAL INDICATING ELECTRICAL INSTRUMENTS

As on previous occasions there was an excellent display of commercial indicating instruments, and all the instruments shown emphasize the very great advances, particularly in workmanship, which has taken place in the manufacture of English instruments of this class during recent years. Messrs Nalder Bros and Thompson Ltd. showed a fine range of their manufactures, including their new Steam Turbo-Alternator Efficiency Indicator (Turner's Patent). This instrument consists of a two element induction wattmeter, working in conjunction with a freely supported drum on which the "Willans line" for the particular machine is traced, a Venturi or other water meter indicating the steam consumption. By means of this instrument a watch can be kept on the machine with a view to ensuring that the general conditions of working are being properly maintained. Causes which, without the instrument, might have continued unnoticed for a considerable period can be rectified without unnecessary or costly delay, and the risk of possibly a serious breakdown can be obviated; while a continuous check on any deterioration or improvement in running is available.

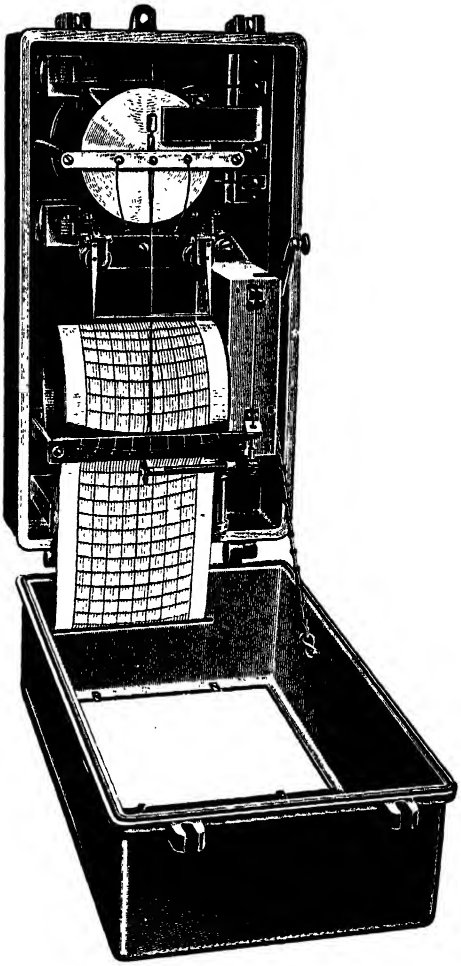
Among many other instruments the firm exhibited a Recording Frequency Meter—which is a development of the well-known N.C.S. deflectional frequency meter. The pen records on the intermittent principle, being tapped on to the chart at intervals of about 20 secs. by a tapping bar actuated by an electromagnet which is energized from Leclanché cells through contacts made and broken by the clockwork driving the chart.

To meet the demand for instruments for use in the control rooms of electricity supply stations where space is a consideration, a very compact arrangement of power-factor meter and ammeter in a rectangular case $5\frac{1}{4}''$ wide and $10\frac{1}{4}''$ long has been developed.

Other combinations are of course possible, such as, for example, wattmeter and voltmeter and wattmeter and ammeter, and as far as possible internal connexions between the instruments are arranged so as to secure a simple terminal arrangement.



Steam Turbo-alternator Efficiency Indicator



Recording Frequency Meter

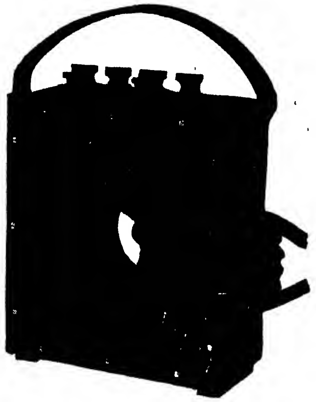
On the stand of Messrs Elliot Bros. (London), Ltd., various types of indicating instruments of their well-known design were displayed, including a fine range of miniature instruments. A Fawssett live cable-core temperature indicator, giving the core temperature of either low or high voltage cables under working conditions, was also shown. It consists of a combination of thermocouples with millivoltmeter so arranged that the reading of the instrument gives directly the core temperature.

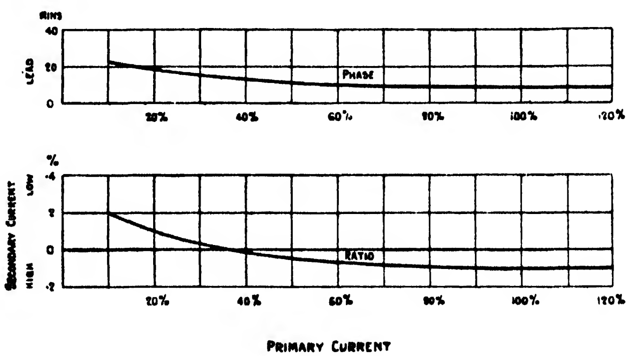
This firm exhibited the Rayworth differential cell testing voltmeter, which has been specially designed for the complete testing of accumulator batteries. It is provided with a differential winding and cadmium electrode. It can be employed as a simple cell testing voltmeter or alternatively will give the potential of each plate against the cadmium electrode. In this way the condition of the plates in a faulty cell may be ascertained; and when used as a differential instrument, with positive terminal connected to the positive plate and negative terminal to negative plate, while the centre terminal is connected to the cadmium electrode, the reading of the instrument enables the state of charge of the cell to be definitely ascertained, the scale being marked so as to read the fraction of the charge still available.

An indicator for obtaining the pressure curve in Explosion Engines, invented by Mr Norman Young, was also shown, consisting of an electrically operated valve and step-by-step contact mechanism. The apparatus may be used to obtain, for instance, the pressure variation in the "scavenging" stroke and also the "explosion" stroke of a Diesel engine, the curves being plotted in a manner similar to that in plotting the wave form of an alternator by means of a Joubert contact maker. The valve is pressure tight against pressures of 1500 lbs. per sq. in. and the apparatus is suitable for speeds up to about 250 R.P.M. By modifications speeds up to 500 R.P.M. can be dealt with.

Messrs Everett Edgcumbe and Co., Ltd., exhibited a wide range of their instruments, including their cube form of photometer for obtaining the mean spherical candle power of glow lamps; and a special three instrument recorder of the relay type intended for traction work, giving records of amperes, volts, and speed; the whole arrangement being carried in a framework slung on springs to minimize the effect of vibration.

They also showed their "Omni Range" portable current transformer of the "precision" type. The excellence of the performance of a transformer of this type, designed for use with substandard wattmeters etc. is shown by the ratio and phase angle curves. The





"Omni-Range" Portable Current Transformer

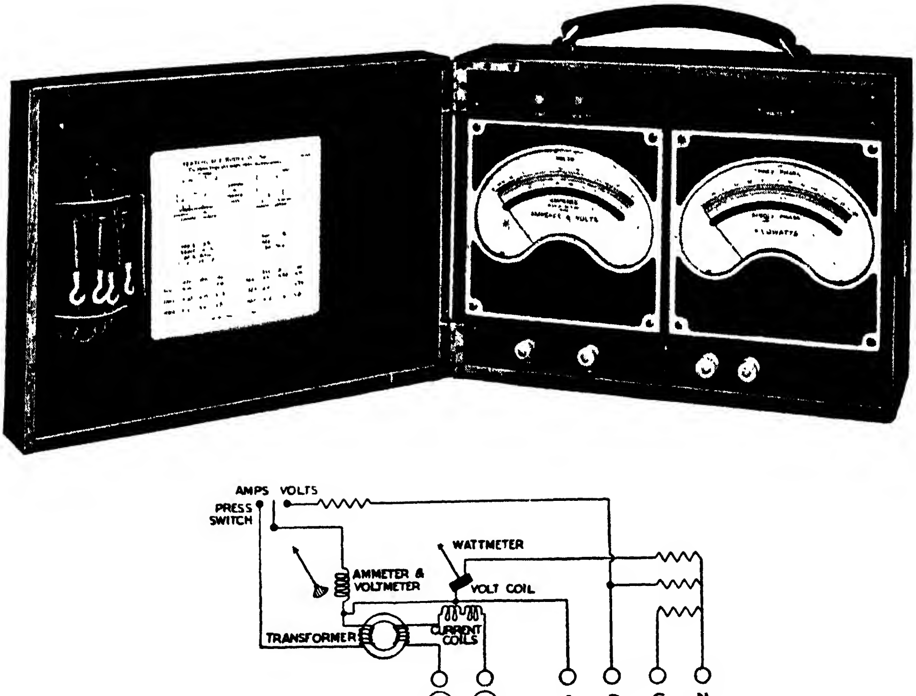
change of ratio from full rated current to one-tenth rated current is less that 0·1 per cent. and the phase displacement only about 2 minutes. Even with a burden of as much as 20 volt-amperes the ratio error does not exceed 0·2 per cent. or the phase displacement 7 minutes at any point within the range. Such figures are believed to be unique.

The great advantage of this pattern of current transformer is that the range of primary currents for which a given transformer is available is almost unlimited—for example a single transformer will give ranges of 10, 40, 80, 160, 200, 400 and 800 amperes; and the transformer only measures 7″ × 7″ × 3½″. The accuracy on all ranges is equally good; in fact the ratio and phase angle curves are identical, which is a feature of the greatest importance in a precision transformer.

The firm exhibited a 44 K.V. bar type current transformer for a full load current of 120 amperes. The advantages of the bar type transformer as compared with the multiturn type, have long been fully appreciated, but hitherto it has not been possible to design such transformers for full load currents of less than 400 or 500 amperes, particularly if power measurements are involved, owing to the large phase displacement introduced between primary and secondary currents.

In the instrument shown the ratio error is not more than ½ per cent. and the phase displacement less than 90 minutes at any current down to $\frac{1}{10}$th of full load. A current transformer having characteristics such as these enables power measurements to be made with

accuracy, and yet has all the advantages of the straight through construction. The handy little phase sequence indicator was also shown. Within the case, which is only 3″ across, is a miniature three phase motor provided with a rotating disc carrying a boldly marked arrow-head, indicating the order of phase sequence, according to its direction of rotation. The flexible leads attached to the instrument are provided with spring jaws so that the instrument may readily be attached to the three points under investigation. The windings of these instruments are such that they can be used on any voltage likely to be met with in practice. The instrument is invaluable for checking over polyphase connexions. A very compact alternating current testing set was exhibited, which, although embodying two instruments only, enables A.C. current, voltage and power to be measured. One movement is of the moving iron type, so designed that it serves alternatively as an ammeter or a



[Everett Edgcumbe A.C. Test Set and connexions

voltmeter at will. The other movement is a wattmeter of the dynamometer type. Currents up to 6 amperes can be dealt with on both the ammeter and wattmeter, but this range can be extended to any required degree by the use of current transformers.

The current terminals are connected in series with the primary of a small current transformer having a ratio of 5/0·05 amperes, and also with the current coils of the wattmeter. When the knob marked "Amps" is depressed the secondary circuit of the small transformer is completed and the pointer of the volt-ammeter indicates the amperes passing. When the knob marked "Volts" is depressed the volt-ammeter winding is connected through a resistance to the appropriate terminals to which the P.D. to be measured is applied, and at the same time the secondary of the small current transformer is short circuited.

The wattmeter volt coil is connected between one terminal and one limb of a star resistance, the other limbs of which are connected to two other terminals. The Wattmeter readings are therefore independent of the position of the "Volts" and "Amperes" press

switch. The dimensions of the set are only 14″ × 10″ × 6″ and it is available for single, two, and three phase measurements at any frequency.

Messrs Record Electrical Co., Ltd., showed examples of their well-known "Cirscale" moving coil and moving iron instruments, and also their "Change Coil" testing set with which a long range of voltage and current measurements, both A.C. and D.C., can be made. The voltage ranges are obtained by means of a soft iron movement and a tapped series multiplier in the usual way. The ampere ranges are given by changing the coil of the second soft iron instrument, which is conveniently arranged so that this can be done rapidly and with a minimum of trouble. Each coil requires an appropriate calibration, and the corresponding scale is therefore printed on a multisided drum, which turns beneath the ammeter pointer. There is therefore only a single scale corresponding to the coil employed beneath the pointer for each range, and confusion is avoided.

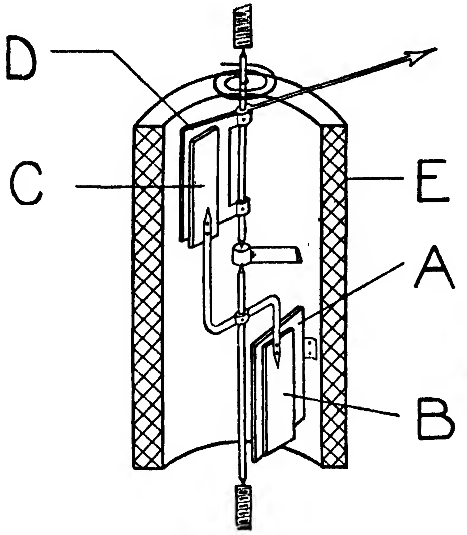
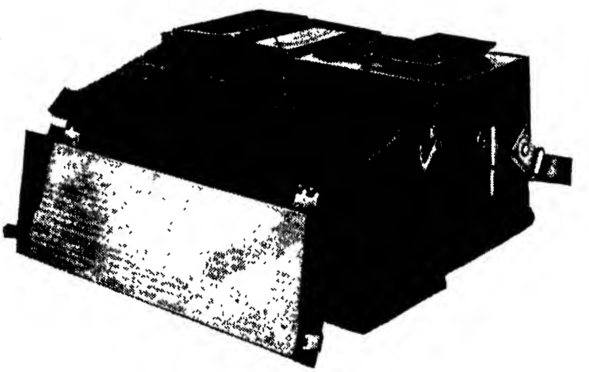


Diagram showing principle of "Cirscale" Moving Iron Instruments


Record Bridge Ohmmeter

Examples of the compact Record Ohmmeter were also exhibited, in which cobalt steel magnets are employed to produce the field of the moving coil instrument, which is further effectively shielded from external stray fields. A new feature is a bridge ohmmeter of novel design. The ohmmeter movement, generator, and bridge dials are included in a single case, and by means of a plunger switch the instrument is either a bridge deriving its current from the generator or is an ordinary ohmmeter, and only two terminals are necessary for external connexion.

Messrs Evershed and Vignoles, Ltd., have a full exhibit of their standard models of Meg. Megger and Ducter testing instruments, together with their well-known indicating ammeters, voltmeters, and recorders. A development of these latter instruments consists of combining with the recorder an operation recorder which gives the position of a number of distant switches or levers etc. In this way a permanent record of any operation is obtained. It is made up in blocks of 7, 12, or 20 movements; each of which indicates whether a machine is or is not running, or that certain switches are "on" or "off." Each movement is entirely independent of the others and may be operated by direct or alternating current.

The exhibit of the Weston Electrical Instrument Co., Ltd., included a number of laboratory standard dynamometers with a guaranteed accuracy of $\frac{1}{10}$th of one per cent. A number of miniature instruments were also shown, including examples of their radio

frequency ammeters, which employ a thermo-junction in metallic contact with a heating strip; the junction being connected to a moving coil instrument specially designed to work with a small millivolt drop at its terminals.

The small pin jack voltmeter shown is specially designed for radio work. The terminals of the instrument consist of a pair of pin jacks which can be easily mounted at the back of a panel; and no great care is necessary in setting out the holes because the pin terminals at the back of the instrument are adjustable. The range of the instrument is extended by means of a high range stand, the base of which contains the necessary resistance. The resistance of the instrument is of the order of 125 ohms per volt.

Pin Jack Voltmeter

The Foster Instrument Co. exhibited pyrometers, ammeters, and voltmeters employing the excellent "Resilia" moving coil system.

A sparking plug thermo-couple pyrometer was shown, constructed to measure the mean temperature inside the combustion chamber of an internal combustion engine, while at the same time it performs its normal duty as an ignition plug. It is found that the operation of the sparking plug normally interferes but little with the indications of the thermo-couple. There were also a number of the firm's intermittent recorders, including a strip recorder with Resilia movement capable of giving six records in distinguishable colours on a single chart; and an inkless dial recorder which employs carbon paper under a translucent paper dial chart.

Messrs Crompton and Co., Ltd., showed indicating instruments, including examples with fully glazed fronts and cut away dials for educational purposes so that the whole movement and its construction can be examined.

A small testing set, "The Alltest," consists of a moving coil instrument in moulded insulation case, and is provided with shunts which screw directly under the terminals for extending the range as an ammeter and enclosed bobbin resistances for screwing on either top or bottom terminal for building up the voltmeter ranges.

A "Unique" cell tester of similar pattern was also shown in which, by the employment of specially shaped pole pieces, an open scale is obtained at the working ranges.

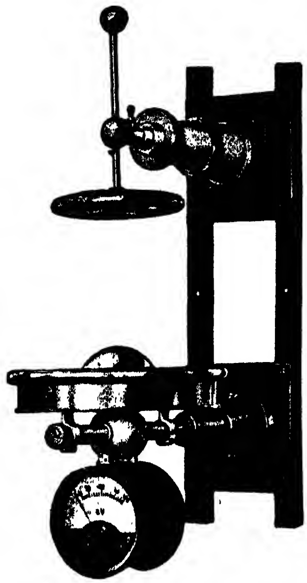
The firm also showed examples of their "Iron Ring" ammeters. In these instruments a pack of ring laminations is carried in an iron case in such a way that the back of the ring projects, leaving an aperture through which a cable can be passed. In the part of the laminated ring within the case a circular gap is formed, and in this gap is pivoted an iron needle of special form. To bring the instrument into operation, the cable carrying the current to be measured is passed through the aperture between the laminated ring and the case already mentioned; this magnetizes the ring and causes the needle to deflect, carrying the pointer over the scale. In this way an ammeter having no winding or insulation as an integral part of its construction is produced.

The Stonebridge Electrical Co., Ltd., showed indicating instruments including high-range electrostatic voltmeters. These instruments are made, up to 6000 volts for A.C. and D.C. and up to 15,000 volts for A.C., with internal series condensers. Between 15,000 and 120,000 volts external series condensers, combined with protecting fuses are preferable.

For laboratory use an instrument up to 400,000 volts is constructed of the movable electrode type. The indicating instrument is placed so that the observer stands in front instead of at the side, as in other forms, and in this way distortion of the electrostatic field due to the earthed body of the observer is avoided.

An Electric Distance Indicator or recorder of angular displacements was shown. The apparatus forms an exceptionally simple and accurate means of transmitting the position

of the indicator of any apparatus having an angular movement. It has a continuous scale and shows any intermediate position between the extremes. Essentially it consists of a transmitting and receiving instrument, both of the ferro dynamic type, and both exactly balanced electrically. The usual step resistances are entirely dispensed with.



Electrostatic Voltmeter
For A.C. up to 120,000 volts

Electrostatic Voltmeter
For laboratory use, A.C. up to 400,000 volts

The M.-L. Magneto Syndicate, Ltd., showed portable peak voltage measuring instruments designed for the measurement of the maximum voltages on an electrical system; particularly when the peak values are in the nature of impulses of relatively short duration as compared with the time interval separating them. Under such conditions the energy available at the moment of occurrence is usually small, and it is important that the capacity and energy consumption of the measuring apparatus shall be reduced to a minimum so as to avoid disturbing the characteristics of the circuit to which it is connected.

A. C. JOLLEY.

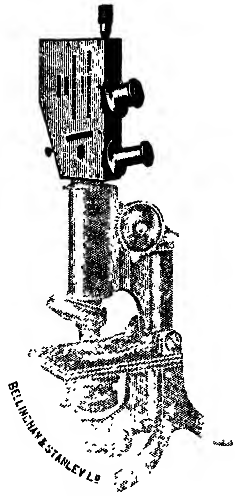
OPTICAL INSTRUMENTS

Photographic Apparatus was exhibited by R. and J. Beck, Ltd., J. H. Dallmeyer, Ltd., Ogilvy and Co., Ross, Ltd., W. Watson and Sons, Ltd., and Wray (Optical Works), Ltd. The chief items of novelty were Messrs Dallmeyer's $f/3{\cdot}5$ "Ultra-speed Dallon Tele-anastigmat" and $f/4{\cdot}5$ "Adon Telephoto" lenses; small reflex cameras ($4\frac{1}{2} \times 6$ cm. size) shown by Messrs Dallmeyer and Messrs Ross; and, on Messrs Ogilvy's stand, a "Leica" camera, fitted with a Leitz $f/3{\cdot}5$ lens, which gives 36 exposures on one length of film.

Telescopes and Binoculars were exhibited by Ross, Ltd., W. Watson and Sons, Ltd., Wray, Ltd., and Carl Zeiss (London), Ltd. The new series of prism binoculars manufactured by Messrs Ross are of special interest, as they give a real field of view up to 11°. They are supplied in magnifications of 6, 7, 9, and 12 diameters.

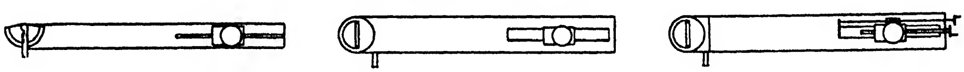
Spectroscopic Apparatus was well represented on the stands of R. and J. Beck, Ltd., Bellingham and Stanley, Ltd., Adam Hilger, Ltd., P. J. Kipp and Zonen, W. Ottway and

Co., Ltd., W. G. Pye and Co., and Carl Zeiss, Ltd. A new model of the Hartridge Micro-spectroscope and a new "Universal" spectrometer, to cover the range from ·2 to 13 μ with quartz, glass, and rocksalt prisms, were shown by Messrs Bellingham and Stanley. Of particular interest was Messrs Hilger's new "Interchangeable" spectrograph, a description

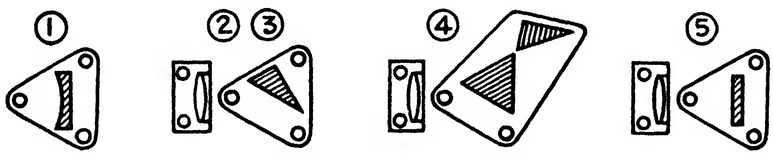


Hartridge Micro-Spectroscope

THE INTERCHANGEABLE SPECTROGRAPH.
By Adam Hilger, Ltd.

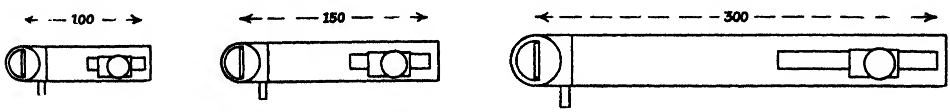


Dark Room Models　　Hand Adjusted Models　　Screw Adjusted Models



Interchangeable Optical Systems

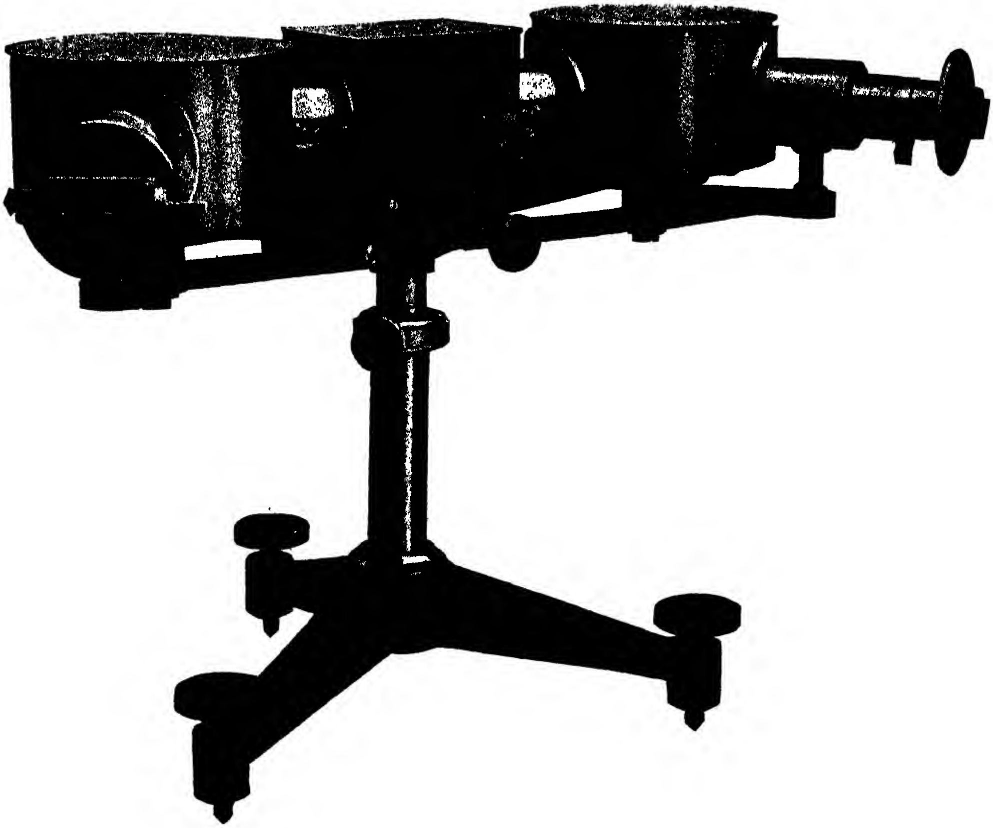
(1) Eagle Mounting Concave Grating.
(2) Littrow Mounting with Quartz Prism and Lens.
(4) ,, ,, ,, one 30° and one 60° Glass Prism and Achromatic Lens.
(5) ,, ,, ,, Plane Grating and Achromatic Lens.



Three sizes of focal lengths approximately 100, 150 and 300 cms.

of which has already appeared in this *Journal*. The fact that any one of five different optical systems may be used with any of the models of this instrument marks a very distinct advance in spectrographic design. Messrs Hilger also exhibited a new model of their medium size quartz spectrograph, constructed entirely of metal and embodying an improved optical system; and new models of their constant deviation wave-length spectrometer and spectrum comparator. An interesting attempt to solve the stray-light difficulty

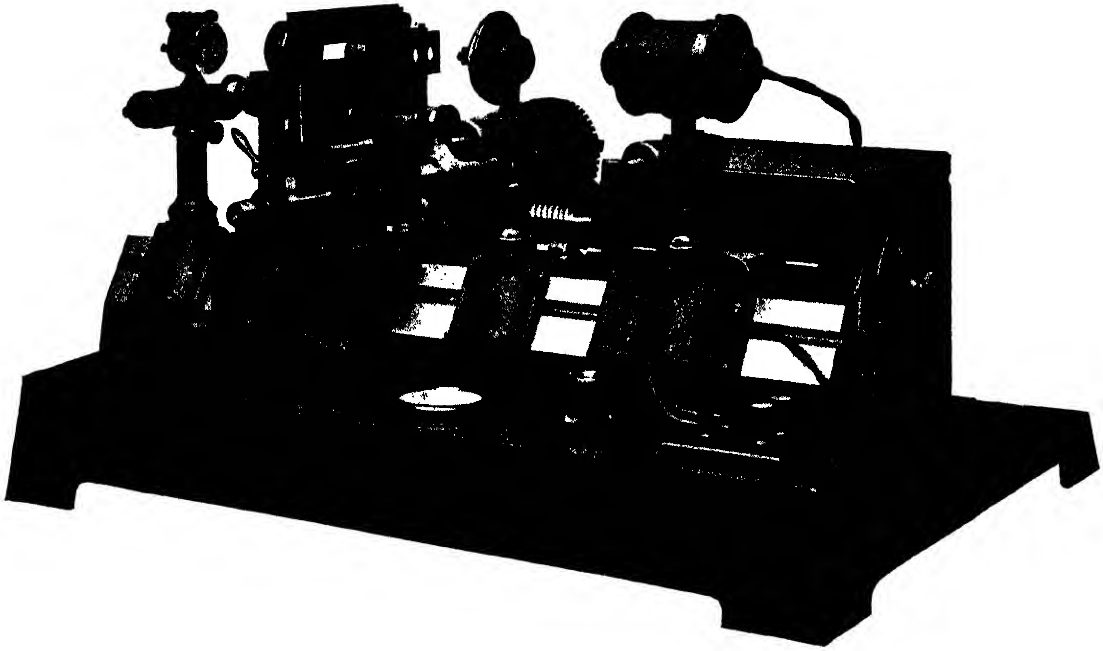
inherent in monochromators was to be found in the double monochromator shown by Messrs Kipp and Zonen. It consists essentially of two monochromators in series, built up as one instrument. The infra-red spectrograph exhibited by the same firm is a well-designed and well-made instrument.



Double Monochromator. Messrs Kipp and Zonen

Polarimeters and Saccharimeters were shown by R. and J. Beck, Ltd., Bellingham and Stanley, Ltd., Adam Hilger, Ltd., and Carl Zeiss, Ltd. The new types of polarimeter tubes in Messrs Hilger's exhibit are worthy of special reference.

Photometers. Bellingham and Stanley, Ltd., exhibited a new model polarization photometer for use in either the visible or ultra-violet regions of the spectrum. A convenient form of portable illumination photometer, originally designed for measuring the comparative whiteness of various powders, was shown by the Cambridge Instrument Co., Ltd., by courtesy of the National Physical Laboratory. The most interesting exhibit in this section was undoubtedly the Moll microphotometer manufactured by P. J. Kipp and Zonen. The instrument is designed to record automatically the variations in density of photographic records—line spectra, Zeeman effect, star spectra, etc. A very narrow beam of light passes through the record and falls on a Moll thermopile. The E.M.F. generated is recorded by a Moll galvanometer; the light from the mirror falls on a drum which is rotated as the photographic plate is made to pass slowly across the narrow beam of light. The plate-holder and the recording drum are driven by a screw (with two different worm gears) which is guaranteed to be accurate to within ·001 mm. Wray (Optical Works), Ltd., exhibited the Ferguson density comparator.



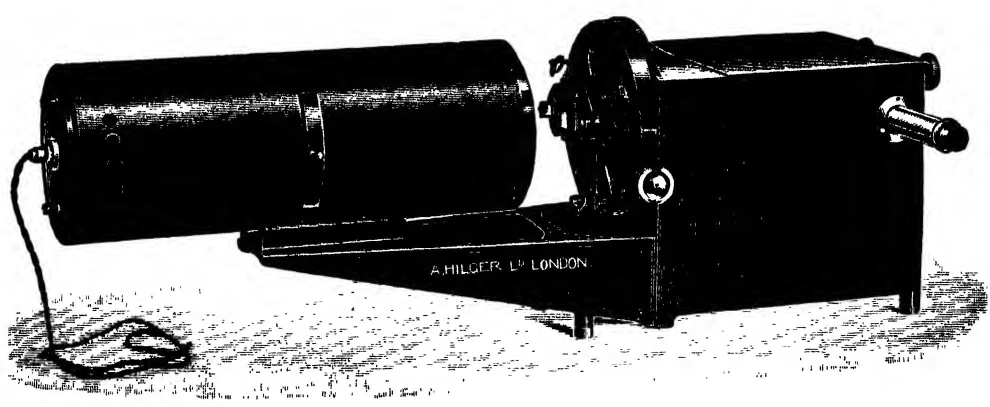
Moll Microphotometer

A new model of the Nutting spectrophotometer was shown by A. Hilger, Ltd. In this model all the components are mounted on a single metal base.

Refractometers of various types were shown by Bellingham and Stanley, Ltd., and Carl Zeiss, Ltd.

Colorimeters. One of the first finished models of the Guild trichromatic colorimeter was exhibited by Adam Hilger, Ltd. A description of this instrument is given in the *Transactions of the Optical Society* (**27**, 2, 110), and a brief sketch of the principle on which it works in this *Journal* (**3**, 8, 273). Tintometers were shown by The Tintometer, Ltd.

J. S. ANDERSON.

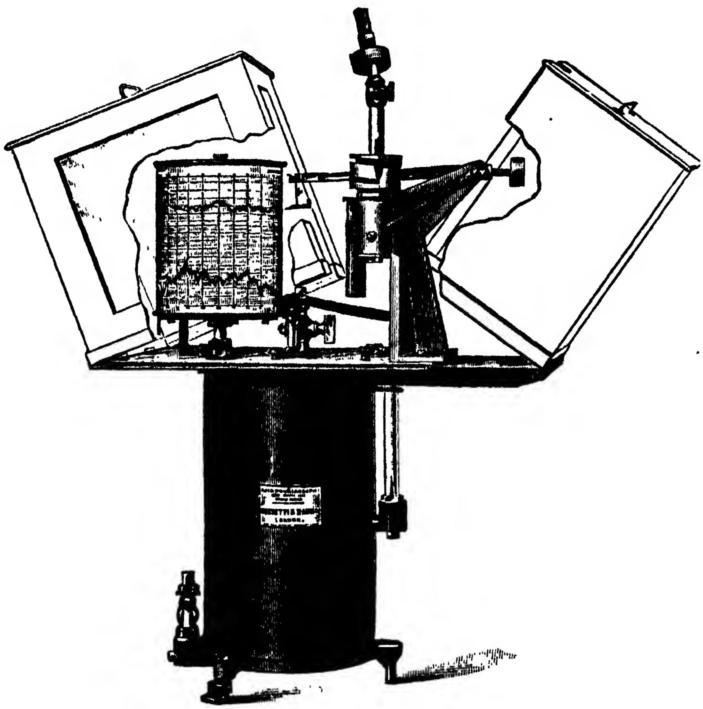


Guild Trichromatic Colorimeter

METEOROLOGICAL INSTRUMENTS

ALTHOUGH the number of exhibits specifically devoted to meteorology was comparatively few and offered little that was new, a careful examination revealed a considerable number of instruments of direct or indirect interest to the meteorologist. For the purpose of a brief review it will be convenient to begin with the exhibits of the recognized makers, passing later to those of firms whose products are of less direct application.

Negretti and Zambra. Among instruments of special interest was an anemo-biagraph registering up to 150 m.p.h. To obtain this range, considerable constructional difficulties appear to have been overcome successfully. We welcome the introduction of 1-inch connecting cocks to this instrument, recent research having shown the great importance of



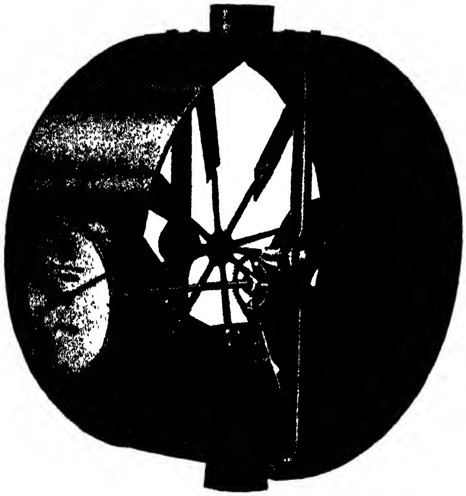
Anemo-biagraph

using pipes of ample bore for conveying the wind pressure to the recorder. Diaphragm anemometry, as shown by a large dial anemometer for comparatively small pressures, is evidently receiving serious consideration. A 16-inch dial wind direction recorder, connected through bevel-gearing, was an attractive exhibit.

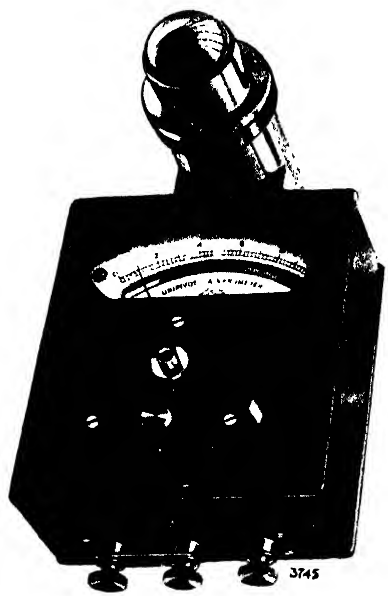
We were interested to notice that Messrs Negretti and Zambra have responded to the great industrial demand for multi-point resistance thermometers and are now making this class of instrument. The convenience of using a single indicator for determining the temperature at a number of widely scattered points is manifest, and the instrument could be used with advantage for certain meteorological purposes.

A barograph covering the remarkable range of 25 inches to 31 inches with a magnification factor of $3\frac{1}{2}$ was among the most interesting instruments on view. A portable ventilated hygrometer of novel design also calls for mention.

Short and Mason, Ltd., were represented by an attractive show of barographs, thermographs, aneroid barometers, air meters and other instruments. The open-scale barographs of this firm, already noticed at the Optical Convention, again attracted much attention. The vane anemometer for low speeds designed by E. Ower* was exhibited. This instrument had previously been shown at the National Physical Laboratory, but was probably new to most visitors.



Ower Anemometer



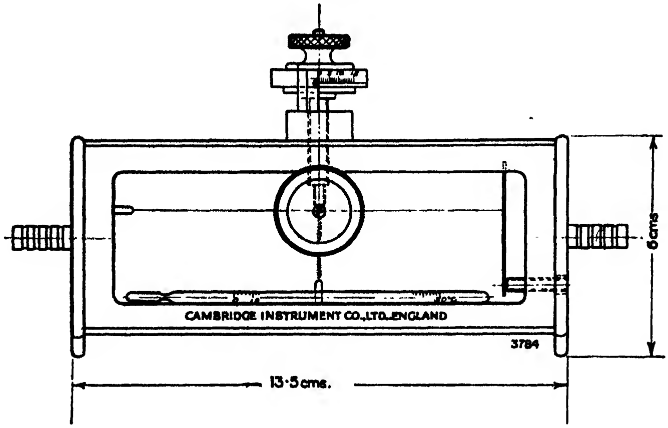
Gorczynski Solarimeter. Cambridge Instrument Co.

The Cambridge Instrument Co., Ltd., had two exhibits of direct meteorological interest. Of these special mention should be made of the portable radiation instrument, designed by L. Gorczynski of Warsaw and named the "solarimeter." In view of the paucity of available instruments for measuring the intensity of solar radiation the advent of so promising a device as the "solarimeter" is much to be welcomed. The instrument is designed to measure the total radiation on a horizontal surface, as in the Callendar radiation recorder. The receiving element is a highly sensitive thermopile of low resistance and low thermal capacity. The thermopile is protected by a small hemisphere of glass, specially selected to give the minimum absorption in the infra red, exhausted to avoid all possibility of moisture condensing on the inner surface. In bright sunshine, such a thermopile will produce an E.M.F. of about 10 millivolts, and it is only necessary to provide a millivoltmeter of suitable sensitivity, connected in parallel with the pile, in order to obtain a complete equipment for determining the intensity of the radiation. In the instrument exhibited, the pile was very neatly mounted on the case of a unipivot millivoltmeter, the resulting instrument being very compact and portable. A scale graduated directly in gram-calories per $cm.^2$ per minute would have been preferable to the scale of millivolts actually used.

The other instrument calling for notice was a direct reading hair hygrometer designed by Dr Ezer Griffiths. In this instrument, the expansion or contraction of a single hair, due to variations in relative humidity, is measured micrometrically. The investigations made at the National Physical Laboratory for the Food Control Board, under Dr Griffiths' supervision, showed quite clearly that a single hair is preferable to a bundle as an indicator

* See *Journ. Sci. Insts.* III, Jan. 1926, pp. 109–112.

of humidity changes. Though the instrument shown would need considerable modification to adapt it to the requirements of the meteorologist, it is interesting to note that a practicable hygrometer employing a single hair has been made available.



Ezer Griffiths Hair Hygrometer

P. J. Kipp and Zonen of Delft, Holländ, exhibited a Gorczynski solarimeter similar in essential particulars to that developed by the Cambridge Instrument Company. Kipp's instrument was fully described in the *U.S. Monthly Weather Review*, Sept. 1926, pp. 381–4.

The *Foster Instrument Company* showed some electrical resistance thermometers of special interest, inasmuch as a device is incorporated for the purpose of compensating any change in battery voltage which may occur. The method, as described in the Company's Book No. 33, seems sound, and a practical demonstration showed that no perceptible change in the indicated temperature occurred when the applied voltage varied between 3·5 and 4·5 volts. The device should be of special use in recorders when opportunities of checking the battery voltages are infrequent.

E. G. BILHAM.

APPLICATION OF THERMIONIC VALVES TO HOT-WIRE ANEMOMETRY.

By BABU LAL GUPTA, M.Sc. Research Scholar, Physics Department, University of Allahabad.

[*MS. received, 22nd November*, 1926.]

INTRODUCTION

WHEN a heated platinum wire is held across a stream of wind, on account of the cooling action of the latter, the resistance of the wire decreases. Attention was drawn to this fact for designing hot-wire anemometers as early as 1909 by Kennelly*. It was developed by Morris†, Bordini‡, and subsequently by Thomas§. The subject was thoroughly investigated

* Kennelly, *Trans. A.I.E.E.* 28 (June, 1909) 363–397.
† Morris, J. T., "The Electrical Measurement of Wind Velocity," *Engineer*, September 27, 1912.
‡ Bordini, U., *Electrician*, 70 (November 22, 1912) 278.
§ Thomas, C. C., *Journal of the Franklin Inst.* (November, 1911) pp. 411–60.

by L. V. King* in 1914 who determined "the convection constants of platinum wire in absolute measure, in order that it might be possible to construct from the easily determined electrical constants of the wire an anemometer capable of giving an accurate measure of air velocity without reference to a calibration in terms of some other form of wind measuring instrument."

These workers measured the current required to maintain the wire at a given temperature which was indicated by its resistance. In the present paper an attempt has been made to utilize the properties of a thermionic triode valve in constructing a very simple type of anemometer.

Brief outline of the theory

For any triode valve if we plot the anode current against grid voltage, keeping both the filament and the plate voltage constant, we get the well-known anode current-grid voltage characteristic curve. The higher the anode voltage, the greater is the displacement of this curve to the left; so that by raising the anode voltage sufficiently high we can shift the curve entirely to the left of the grid zero line. We are, however, concerned with the straight portion only, as the slightest change in the grid potential in this region produces a comparatively much larger change in the anode current. Moreover, equal changes in the grid potential produce equal changes in the anode current. Now if the wire be electrically heated and one end of it be connected to the grid of a thermionic valve and the other to the filament, the grid will acquire a voltage equal to the P.D. across the wire, and a definite amount of current will be flowing in the anode circuit. Any change in the resistance of the wire will change the grid potential and consequently the anode current.

Description

In series with a short length of platinum wire, about 0·05 mm. in diameter, was connected a variable resistance of manganin wire, a 2-volt battery, and an ammeter. Usually 0·5 amp. current was passed through the wire, which made it red hot. The platinum wire was held across a brass tube of 1·5 cms. diameter. One end of the wire was connected to the grid and the other to the negative end of the filament battery. It is advisable to give the grid a slightly negative grid bias in order to prevent effectively any current from flowing into the grid circuit. A schematic diagram of the arrangement that was tried is given below:

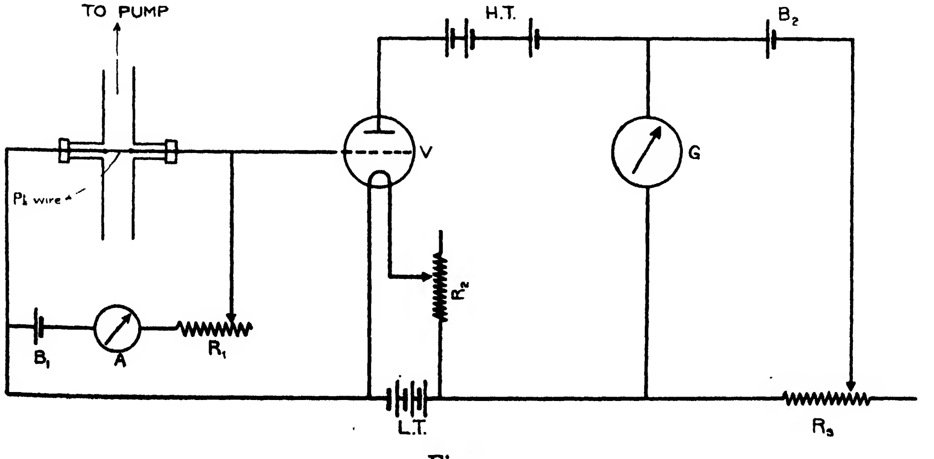


Fig. 1

* King, L. V., "The convection of heat from small cylinders in a stream of fluid," *Phil. Trans. Roy. Soc.* ser. A. **214**, 373–432.

The steady anode current was balanced by an auxiliary battery B_2 in series with the variable resistance R_3. This device enables a micro-ammeter or a more sensitive type of instrument to be used. The instrument G was actually a unipivot micro-ammeter. The air was sucked through the tube at various speeds which was indicated by a Robinson four-cup type anemometer. For every speed of the air there was a definite deflection of the needle in G which remained stationary as long as the speed remained constant. After noting down each reading, the draught of air was cut off and it was noticed that the initial reading of the micro-ammeter remained sensibly the same. Fig. 2 shows the relation between the deflections of the micro-ammeter and the velocities of air in metres per second.

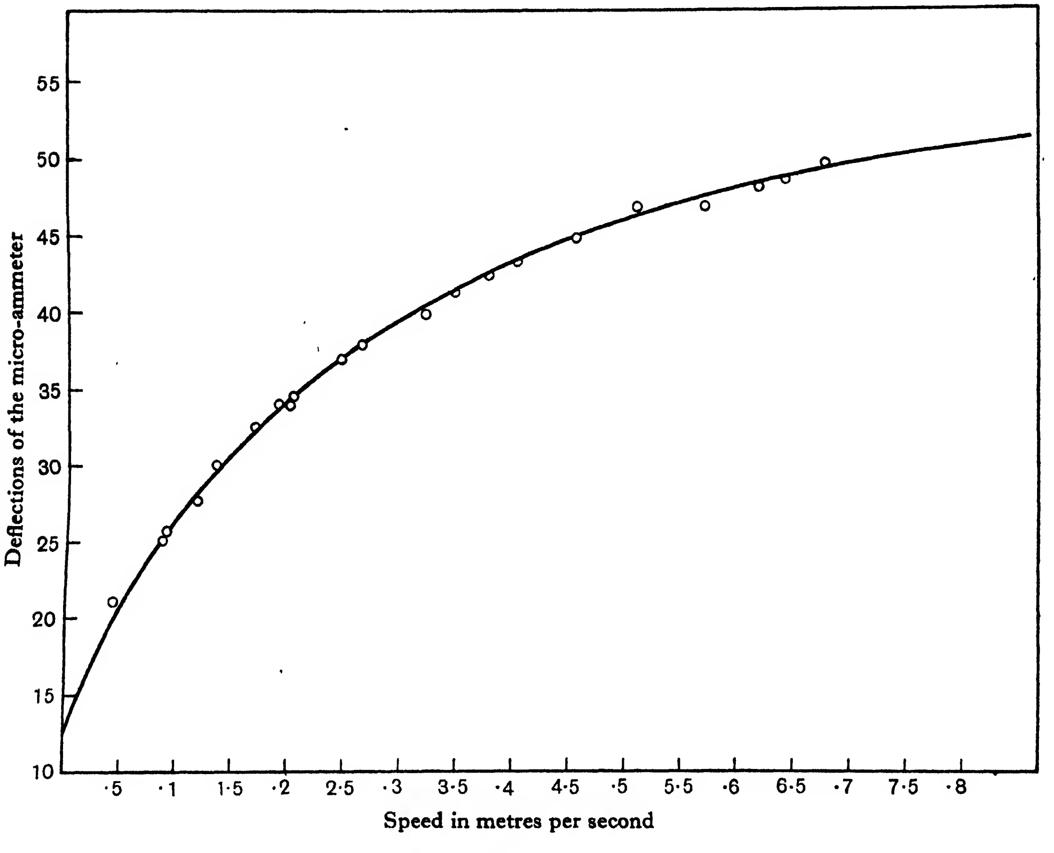


Fig. 2

Discussion

1. The curve should as a matter of course meet the axis of X towards the positive side instead of cutting the axis of Y. This discrepancy is due to the fact that the Robinson type of anemometer is insensitive for very small velocities. It actually failed to record any speed even though the micro-ammeter showed as much as 15 degrees deflection.

2. At low speeds the anode current changes rather rapidly, but as the speed rises the change in the anode current is more gradual. This is quite natural; for as the temperature of the wire approaches room temperature, it will require a comparatively much larger change in the speed to vary the resistance of the wire by the same amount.

3. It is desirable to calibrate the instrument directly by means of a gasometer, especially at low speeds. This will eliminate one important source of error.

4. The introduction of one or more amplifying valves before the final detector will greatly increase the sensitiveness of the instrument. It is intended to develop the instrument on the lines suggested in this and the previous sections.

As the above work was in progress, the attention of the writer was drawn to a paper by Teggan*. He has also employed a thermionic valve for measuring the velocity of air currents. He differs, however, in two essential points. He has put the platinum wire in series with the filament so that a change of resistance in the latter causes a change in the electron emission and consequently a change in the anode current. There does not exist a very simple relation between the two phenomena. He has also connected the grid to the plate and has thus virtually turned the triode into a diode.

The writer takes this opportunity of thanking Professor M. N. Saha, for suggesting this work and helping him in carrying it out.

LABORATORY AND WORKSHOP NOTES

DRILLING HOLES IN GLASS. By B. BROWN, B.Sc. (Eng.)

[*Manuscript received* 31. 1. 27.]

In the making up of apparatus one sometimes comes to a point where a very neat device might be utilized were it possible to drill a hole through a particular glass vessel. It is known generally that holes in glass are drilled by use of a copper tube and an abrasive such as emery powder. There is nothing at all wrong with this method, but a special tool is necessary and it is not always convenient to have such things prepared—the hole is required immediately. The writer has found the following method very useful indeed, as it may be applied with material always at hand.

For the drill take one of the ordinary type and sharpened in the usual manner. Generally speaking, the actual size of the hole is of small importance. If, however, it is necessary to keep the diameter to within fine limits, it is better to choose a drill about 0·005″ smaller than the hole required.

A cutting compound must be made up and this should consist of a saturated solution of camphor in spirits of turpentine. The drill should be run slowly and a copious supply of the compound applied. A good cutting pressure should be given to the drill, but this must not be so great as to cause flexure. It is very necessary to have a good support beneath the glass part which is being cut. After a short time a smooth hole will result, but one must not expect the cutting to be done at the same rate as for, say, mild steel.

In the laboratory the file is a most useful tool for the cutting of glass tube and rod. By use of the solution mentioned above much better results will be made possible; indeed any shape may be cut out with the expenditure of a little care. We suggest that all who may sometime have need to treat with glass make the experiments—they will most certainly be surprised at the results.

ON SPRINGS

[*Manuscript received* 14. 1. 27.]

It is not very commonly recognized in the workshop that the hardening or tempering of a steel spring does not alter the rigidity of the spring, but it does change its elastic limit and enables the spring to withstand higher stress.

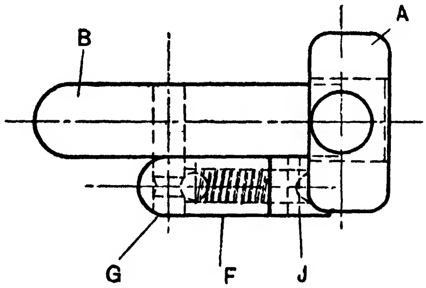
A defect frequently found in the springs of scientific instruments is that they are too short and stiff, and in consequence their strength varies considerably through their working

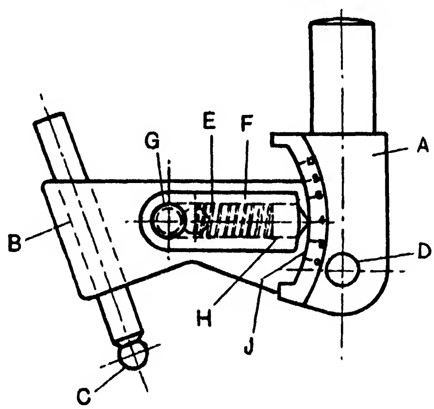
* Teggan, J. A. C., *Phil. Mag.* (May, 1926), pp. 1117–20.

range. In order to avoid this defect, such springs must have an initial set which is large in comparison with the variation of set occurring during operation. But this condition makes it generally impracticable to do successfully what is commonly attempted when means are provided for varying the initial set in order to vary the spring's operative strength. A spring which can be so varied is inevitably one whose strength varies substantially through its working range, unless that range is short.

This is one of the many everyday problems of design which our textbooks and schools disregard.

The solution (found here many years ago) is to use a spring with large initial set, and to vary its radius of action (i.e. its turning moment) about some axis. This may be done in many ways, one of which is shown in the accompanying illustration, which represents part of a Taylor-Hobson lens polishing machine. The piece *A* is attached to one of the machine





spindles and carries the crank arm *B* with the ball-pointed finger *C* which engages the polishing tool and moves it in a circular orbit. In order to put pressure on the tool through the finger *C*, the arm *B* is pivoted to *A* at *D* and is pressed downward by the helical compression spring *E* (contained in the tube *F*) which urges a plunger *H* into contact with the abutment surface *J* on the piece *A*. In order to vary the pressure, without variation of the initial set on the spring, the tube *F*, with the spring and the plunger, are movable about a pivot *G* on the arm *B*, and the abutment surface *J* forms an arc of a circle centered about *G*. When the device is set so that the plunger *H* thrusts in a straight line joining the axes *G* and *D*, the pressure on the ball *C* is zero, and, as shown by the graduation, the pressure can be increased from zero to 10 lb. by setting the plunger progressively to other parts of the abutment surface *J*. The spring *E* has a length, when free, two or three times its length when confined in use, and, as its working range of motion is relatively small, the pressure on the ball *C* is substantially constant through the working range for every available pressure.

THE TAYLOR-HOBSON RESEARCH LABORATORY, LEICESTER.

TESTING FOR THE PERMANENCE OF THE RATIO AND PHASE ERRORS OF SERIES TRANSFORMERS. By G. W. STUBBINGS, B.Sc., A.Inst.P., A.M.I.E.E.

Mr Isaac's interesting paper in the December issue of the *Journal* raises the important question of the most expeditious method of periodically checking the accuracy of standard series transformers. It may be pointed out that if, at the time that the errors of such a transformer are tested, the volt-ampere characteristic of the secondary winding, with the primary open-circuited, be obtained, it will merely be necessary, for future checks, to ascertain that this characteristic can be repeated. This test is very much easier and quicker than a re-test of the ratio and phase errors. The writer may perhaps add a few particulars of an instance in which this method proved very useful. A 1200/5 Weston portable series transformer had its secondary winding open-circuited, due to a faulty short-circuiting switch, when the primary was carrying about 700 amperes. A point on the saturation curve, after this had occurred, gave 5·2 secondary volts with 74·1 milli-amperes. According to the original saturation curve, the exciting current for this voltage should have been 66·2 milli-amperes. The phase error, and the uncompensated ratio error at this voltage had therefore been increased by about one-eighth. The transformer was magnetized to 60 volts in the usual way, and the exciting current was gradually reduced to zero. A second test of the current for 5·2 volts gave the original figure of 66·2 milli-amperes, showing that the former accuracy of the transformer had been restored. Thermal instruments of the indicating type were used for the above test, and the observed voltage included the drop in the milli-ammeter. Provided the same method of connexion is used in all tests, the error so caused is not material, and in any case, for measurements of commercial accuracy, it is a matter of comparative indifference.

TABULAR INFORMATION ON SCIENTIFIC INSTRUMENTS

The following table gives particulars of various forms of Electrostatic Voltmeters as furnished by their respective manufacturers. A separate copy of this table can be obtained by any subscriber on application to the Secretary of the Institute of Physics, 1 Lowther Gardens, Exhibition Road, London, S.W. 7, and bound copies of the twelve tables which appeared in the last volume can be obtained from the same source, price 3*s*. 6*d*. post free.

XVIII. ELECTROSTATIC VOLTMETERS

Type	Cat. No.	Range (volts)	Length: Pointer	Length: Scale	Accuracy % of top reading	Periodic time	Damping	Remarks	List Price £	s.	d.
Maker:—Messrs Cambridge Instrument Co., Ltd., 45 Grosvenor Place, Westminster, S.W. 1.											
Ayrton-Mather reflecting	42411	1–9	Mirror radius	—	0·1	16 secs.		Internal fuse provided	40	0	0
		1·5–11	1 metre.	—	—	11 ,,	Vane fitted		38	0	0
		4–30	Other radii to order	—	—	7 ,,	to needle mirror		36	0	0
Ayrton-Mather pointer type	42421	20–130	107 mm.	120 mm.		—		Ditto	19	0	0
		80–250	107 ,,	120 ,,	B.E.S.A.	—	Spiral		17	10	0
		100–300	107 ,,	120 ,,	sub-standard	—	spring		17	10	0
		200–600	107 ,,	120 ,,		—	control		17	10	0
		400–1000	107 ,,	120 ,,		—			17	10	0

Type	Cat. No.	Range (volts)	Length: Pointer	Length: Scale	Accuracy % of top reading	Periodic time	Damping	Remarks	LIST PRICE
Maker:—MESSRS EVERETT EDGCUMBE & Co., LTD., COLLINDALE WORKS, HENDON, N.W. 9.									£ s. d.
Dwarf 2½" dial.	—	0–500 up to 0–3,000	1 5/16"	2½"	2	2 secs. Time to come to rest	Pneumatic	A.C. or D.C.	According to range, etc.
Switchboard 8" dial.	—	0–2,000 up to 0–8,000 A.C. or 0–20,000 D.C.	3 3/16"	4½"	1	3 secs.	Pneumatic	A.C. or D.C. The A.C. ranges can be extended up to 25,000 volts by means of series condensers	
Switchboard 12" dial	—	Ditto	5½"	7"	1	5 secs.	Pneumatic		
Portable	—	Ditto	5½"	7"	1	5 secs.	Pneumatic		
Extra high voltage	—	0–10 K.V. up to 0–500 K.V.	3⅜"	5½"	3	1·5 secs.	Pneumatic	A.C. or D.C. These voltmeters are direct acting and are each provided with three ranges	
Maker:—MESSRS KELVIN BOTTOMLEY & BAIRD, 18 CAMBRIDGE STREET, GLASGOW.									
Multicellular portable test table type	1118	20– 80	5½"	6"	B.S. 1st grade or sub-standard grade	—	By oil dashpot	Mirror scale with knife-edge pointer or ordinary pointer	22 0 0
	1119	30–120	5½"	6"		—			22 0 0
	1120	40–160	5½"	6"		—	Ditto		22 0 0
	1121	60–180	5½"	6"	Ditto	—	Ditto	*Can be supplied as "Reflecting Instrument"*	22 0 0
	1122	80–300	5½"	6"	Ditto	—	Ditto		22 0 0
	1123	200–600	5½"	6"	Ditto	—	Ditto		22 0 0
Ditto for wall or switchboard mounting	919	20– 90	6½"	6½"	Ditto	—	Ditto	Ditto	22 0 0
	920	40–160	6½"	6½"	Ditto	—	Ditto	Ditto	22 0 0
	921	80–260	6½"	6½"	Ditto	—	Ditto	Ditto	22 0 0
	922	100–300	6½"	6½"	Ditto	—	Ditto	Ditto	22 0 0
	923	200–560	6½"	6½"	Ditto	—	Ditto	Ditto	22 0 0
	924	200–650	6½"	6½"	Ditto	—	Ditto	Ditto	22 0 0
Unicellular (three range)	1128	500–2,000	7½"	5"	As. Br. Eng. Stds. Specification for instruments of this type	—	Mechanical	Range changed by changing control weights	21 0 0
		1,000–4,000	7½"	5"		—	,,		
		2,000–8,000	7½"	5"		—	,,		
Ditto	1129	500–3,000	7½"	5"		—	,,	Ditto	21 0 0
		1,000–6,000	7½"	5"		—	,,	Ditto	
		2,000–12,000	7½"	5"	Ditto	—	,,	Ditto	
Ditto	1130	1,000–5,000	7½"	5"	Ditto	—	Ditto	Ditto	31 10 0
		2,000–10,000	7½"	5"	Ditto	—	Ditto	Ditto	
		4,000–20,000	7½"	5"	Ditto	—	Ditto	Ditto	
Attracted plate	1133	5,000–30,000	6"	6"	As. Br. Eng. Stds. Specification for instruments of this type	—	Electro-magnetic	Single range	60 0 0
Ditto	1134	5,000–30,000 and 20,000–100,000	12"	12"		—	Ditto	Two ranges by changing control weight	110 0 0
Maker:—MESSRS NALDER BROS. & THOMPSON, LTD., 97 *a* DALSTON LANE, E. 8.									
Iron-cased switchboard pattern	—	800–1200	5"	7"	·5	7 secs.	Electro-magnetic, permanent magnet, acting on copper or aluminium disc		16 10 9
		700–1500	,,	,,	,,	,,			16 10 9
		1200–1800	,,	,,	,,	,,			16 10 9
		1000–2000	,,	,,	,,	,,			16 10 9
		1600–2400	,,	,,	,,	,,			16 10 9
		1000–2500	,,	,,	,,	,,			16 10 9
		2000–3000	,,	,,	,,	,,			17 8 9
		1500–3000	,,	,,	,,	,,			17 8 9
		2200–3200	,,	,,	,,	,,	Ditto		18 0 0
		1500–3500	,,	,,	,,	,,	Ditto		18 0 0
		3500–4500	,,	,,	,,	,,	Ditto		19 2 6
		3000–5000	,,	,,	,,	,,	Ditto		19 2 6
		2000–6000	,,	,,	,,	,,	Ditto		20 5 0
		4000–6000	,,	,,	,,	,,	Ditto		20 5 0
		5000–6500	,,	,,	,,	,,	Ditto		21 7 6
		2500–6500	,,	,,	,,	,,	Ditto		21 7 6
		6000–7500	,,	,,	,,	,,	Ditto		23 13 0
		3500–7500	,,	,,	,,	,,	Ditto		23 13 0
Maker:—MESSRS STONEBRIDGE ELECTRICAL Co., LTD., VICTORIA ROAD, NORTH ACTON, W. 3.									
GCiv	56001 56008	min. 0–1,500 max. 0–6,000	92 mm.	105 mm.	± 1·5 %	3–4 secs.	Air damping nearly aperiodic	Switchboard mounting projecting pattern. D.C. and A.C.	14 10 0 *to* 16 5 0
Gdiv	56011 56012	min. 0–2,000 max. 0–6,000	110 mm.	125 mm.	± 1·5 %	approx. 4 secs.	,,	D.C. and A.C.	17 10 0 *to* 20 0 0
Gdv	56021 56027	min. 0–2,000 max. 0–6,000	110 mm.	125 mm.	± 1·5 %	approx. 4 secs.	,,	Switchboard mounting projecting pattern. D.C. and A.C. 1 terminal connected to earth	15 0 0 *to* 17 10 0
Gdfv	56031 56037							As above but flush pattern	16 0 0 *to* 18 10 0
Gldv	56041 56045	min. 0–6,000 max. 0–15,000	110 mm.	125 mm.	± 2 %	approx. 4 secs.	,,	Switchboard mounting projecting pattern. A.C. only	19 0 0 *to* 23 10 0
Gldfv	56051 56055							As above but flush pattern	19 15 0 *to* 24 0 0
GLdv	56101 56102 56151 56163	min. 0–20,000 max. 0–120,000	110 mm.	125 mm.	± 2 %	approx. 4 secs.	,,	Wall mounting. A.C. only 1 terminal connected to earth	31 0 0 *to* 46 10 0 50 0 0
GLdjv	56131 56142	max. 0–350,000						As above but fitted with H.T. fuse	37 0 0 *to* 58 0 0
GLdzv	56171 56183	min. 0–20,000 max. 0–120,000	110 mm.	125 mm.	± 2 %	approx. 4 secs.	,,	Wall mounting. A.C. only. Cylinder condenser	40 0 0 *to* 67 0 0
GCpff		max. 0–500,000		200 mm.	± 1·5 %	approx. 5 secs.	,,	Flush pattern. D.C. and A.C.	Prices on application

JOURNAL OF SCIENTIFIC INSTRUMENTS

VOL. IV | APRIL, 1927 | NO. 7

SECOND LECTURE (JANUARY 5TH) AT THE ANNUAL EXHIBITION OF THE PHYSICAL AND OPTICAL SOCIETIES

PROGRESS IN THE DESIGN AND CONSTRUCTION OF ELECTRICAL INSTRUMENTS. BY DR C. V. DRYSDALE.

(*Continued from p.* 184)

The two other chief points which require care in the design of soft-iron instruments are the keeping down of hysteresis and wave form errors, and here again nickel-iron alloy used with appreciation of its limitations as regards saturation, and well laminated to keep down eddy currents, should be of great assistance.

Extension of Range of A.C. Instruments

As shunting has hitherto been inapplicable, and is unlikely to be of extended application owing to the power consumption it would involve, current transformers have been substituted, and great progress has recently been made in improving the ratio and phase relations of such transformers—so much so that some of them can now be used with ammeters and wattmeters with a fairly high degree of accuracy, and with the great advantage as regards high voltage circuits of isolating the indicating instrument from the high tension supply. The introduction of the nickel-iron alloys however seems to offer opportunities for still greater improvements, as the vector difference between the primary and secondary ampere-turns is the no-load ampere-turns required for the core, which is made up of the magnetizing and coreloss ampere turns; and as permalloy or mumetal has a much higher permeability and lower hysteresis than any of the older magnetic materials, it should give excellent results, provided that care is taken in the design to work over the best portion of the magnetization curve. It is believed that Messrs Everett Edgcumbe have already employed this alloy with remarkable results in their "Precision" transformers.

The use of current transformers permits of ammeters and wattmeters being made and calibrated for a single range of say 5 amperes, and of employing transformers to extend this range by any multiple desired.

Notwithstanding the attractive features of transformers, however, they fail us when we require to use an instrument for both D.C. and A.C. work; and as soft-iron ammeters, and wattmeters, are equally suitable for either, some device for extending the range which is equally suitable for both forms of supply is much needed for test-room instruments. In order to avoid eddy current errors, it is necessary to subdivide the current winding into a number of independent circuits and the obvious method of changing the range in this case is to combine these circuits in series and parallel as required. In the earliest forms of Ayrton-Perry ammeter, although these were only intended for direct current measurement,

the coil was wound with ten independent circuits which were connected either all in series or all in parallel by a barrel commutator. When the writer took up the problem of constructing an accurate wattmeter, the need for stranding the current coils became evident, and he introduced a barrel form of commutator which enabled the circuits to be combined in any of the four arrangements $\frac{10}{1}$, $\frac{5}{2}$, $\frac{2}{5}$, or $\frac{1}{10}$, giving current ranges in the ratio 1, 2, 5 and 10. Wattmeters have been constructed with such commutators up to a maximum current of 250 amperes, giving an accuracy of well within 1 per cent. from 1 to 250 amperes.

The convenience of this arrangement has led the writer to consider its best application to testing instruments generally. In order to apply it to soft-iron instruments it is obviously necessary to find some simpler and cheaper device than the barrel commutator which has the disadvantage besides costliness of requiring the whole of the current to be conveyed into the barrel through the bearings, thus making it stiff to turn for large currents. Fig. 3 shows an attempt at a more simple construction, which although needing improvement, indicates the principle which seems correct. Before describing it, however, a word should

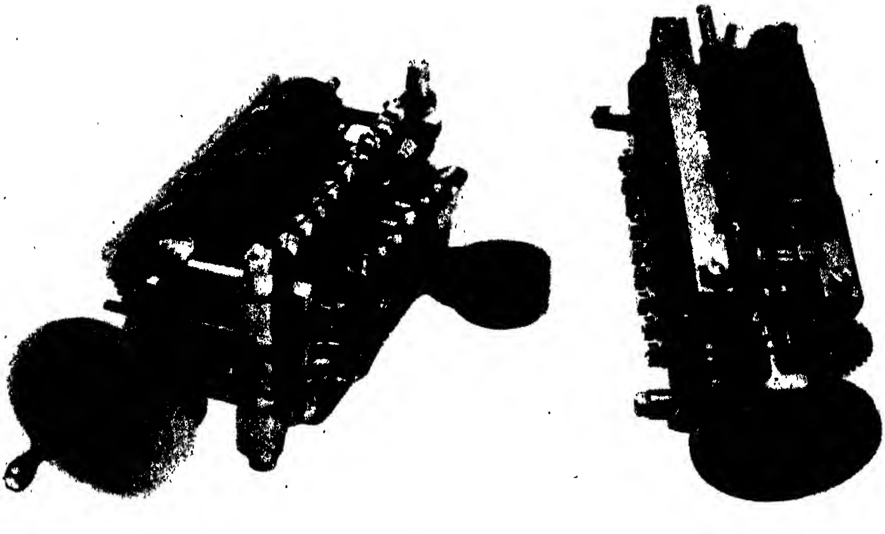


Fig. 3

be said concerning the construction of the multiple coil. Stranding becomes troublesome, bulky, and unmechanical for large currents, and the sorting out of the ends and connexion to the commutator is an additional trouble. But by making the conductors of strip form it is possible to make a neat subdivided coil of high space factor in which the separate circuits all have practically the same resistance and inductance, and in which the ends of the strips naturally come out in the suitable order for the commutator and can in fact be made to form the brushes without any soldered joints. Figs. 3 and 4 in the October issue of this *Journal* showed the form of the strips for a 2—20 turn coil suitable for a 150 ampere ammeter and the coil formed from them. As the inner turn in one half of the coil becomes the outer in the second half, and so on, all the circuits are approximately of the same area and magnetic effect, so that the current tends to divide itself equally between them when in parallel. The ends of the strips are widened so as to decrease the current density and are folded over with a steel strip between so as to form stiff but springy ends, and the two halves of the copper strip are bent over and split to form the contacts. Two bus-bars with terminals lie on the two sides of the strips, which normally bend outwards and make contact with these bars, so that the whole of the circuits are in

parallel across them. Two cams of insulating material, geared together, are mounted outside the strip and these when turned through a right angle push each alternate pair of contacts away from the bars but into contact with each other, giving the combination 2 series 5 parallel and halving the range. A further quarter turn of the cams releases these contacts, but presses the middle pair into contact giving the combination 5 series 2 parallel; while the last quarter turn puts all the circuits in series. This arrangement is cheaper and easier to turn than the original barrel commutator, and has the minimum number of contacts of the most simple form. For an ammeter or wattmeter it is desirable that these contacts should be sufficiently long to avoid opening the circuit when changing over, but if they are shortened so as to break circuit in the intermediate positions, the commutator can be used with accumulators or transformers for conveniently throwing them into series-parallel combinations. The turning of the cams can also easily be made to move a number plate behind the instrument dial and bring the correct figures into view through holes, so that the instrument is always direct reading.

In the case of self-contained testing sets, the principle can be advantageously extended, by making the ammeter and wattmeter both with multiple windings which are connected together and operated by a single commutator, so that the ranges are simultaneously changed; while for permanent calibrating outfits the circuits may be extended to include the regulating rheostats, accumulators, and transformers, giving the most efficient combination in each case. The writer ventures to suggest that this subject is worth the attention of instrument manufacturers, and that if a really satisfactory and cheap form of series-parallel commutators can be produced, combined A.C. and D.C. testing sets of high accuracy and range and great portability would prove highly popular.

Dynamometer Instruments

The dynamometer principle appears to be best suited to standard instruments and to wattmeters. Voltmeters of this type may also survive as they form convenient sub-standard instruments for both direct and alternating voltages of lower value than can be easily dealt with by electrostatic instruments, but the deflectional dynamometer ammeter seems unlikely to persist, in spite of its good electromagnetic efficiency. Such an instrument is simply a pivoted variometer, and by careful construction of the coils a variation of about 10 to 1 in inductance can be obtained, implying an electromagnetic efficiency of about 90 per cent., but the moving coil has essentially a rather low ratio of torque to inertia owing to the weak field of the fixed coil.

For deflectional wattmeters, however, the dynamometer instrument holds the field and is likely to do so. It is curious that although this instrument was devised by Professors Ayrton and Perry about 1881, the theory they evolved concerning its inductive errors led them to distrust its accuracy, and to devise electrostatic and other much less satisfactory methods of measuring A.C. power; and it was not until 1901, when the present writer developed an unambiguous theory of its errors, that confidence was restored in it*.

The type of wattmeter based on this theory, and the similar type introduced shortly after by Messrs Duddell and Mather, have persisted almost unchanged to the present day; and in 1902 the writer made the first double wattmeter for polyphase measurements, on the same lines.

* An interesting incident which did a great deal to confirm the distrust of dynamometer wattmeters occurred in the famous early controversy over the relative merits of open and closed iron circuit transformers, when Mr Swinburne produced a wattmeter which appeared to establish the higher efficiency of the former. Mr Swinburne's wattmeter was however constructed with so much metal that the eddy currents caused the instrument to read low on lagging loads, and therefore gave too low a value for the input into the primary of his highly inductive transformer.

These instruments were all of the torsional substandard type, but from that time on, deflectional dynamometer wattmeters have been developed by a number of manufacturers, and many of them are now very satisfactory and accurate instruments for ordinary supply frequencies. The most serious source of error, especially as regards high current wattmeters, is the production of eddy currents in metal supports or in the coils themselves, while the elimination of metal supports renders the instrument unmechanical and liable to distortion with heating; but the use of alloys of high specific resistance and so disposed as to be as far out of the field as possible enables this error to be reduced to nearly an unappreciable amount, and Prof. Mather has recently shown that the introduction of a certain amount of inductance into the moving coil enables any residual eddy currents to be compensated for all ordinary frequencies. The risk of eddy currents or skin effects in the main coils themselves can be greatly reduced by stranding them and taking care to make the area or inductance of the several elements as nearly as possible equal, in some such way as has already been described, and this enables the range to be easily varied by a series-parallel commutator, as was done in the original standard instruments above referred to.

For currents of 1000 amperes and over, however, stranding presents great difficulties, and in this case the concentric or toroidal form of instrument, as designed by Agnew and by Moore, is undoubtedly the best. It is based on the well known and valuable but little used principle that the annular magnetic field in the interspace between the conductors of a concentric cable is completely independent both in magnitude and phase of the "skin effect" or distribution of the current in the various layers. If therefore a wattmeter is made of two thick concentric tubes as going and return conductors, and the moving coil is mounted in the field between them, accurate measurements can be made with currents up to 5000 amperes or more, especially as the conductors can be easily cooled by water circulation. In the Moore instrument made by Messrs Kelvin, Bottomley and Baird* the outer tube is replaced by a cage of cylindrical conductors which probably realizes the principle sufficiently nearly, and permits of the moving coil being seen and more easily centred.

The new nickel-iron alloys appear to have a valuable application to wattmeters. Several attempts have already been made to increase the field due to the current coils, by employing laminated iron, but although a certain gain has been effected, the application of the principle has been seriously limited by the hysteresis lag in the iron, which has necessitated a high ratio of gap to iron reluctance. Since the hysteresis loss in permalloy or mumetal is only about a fifth to an eighth of that of soft-iron, it should be possible to increase the field strength in about this ratio, without introducing serious errors, and thus to increase the torque and robustness of indicating wattmeters and also to confine the field so as to enable metal supports and nickel-iron screening to be employed without great risk of eddy current errors. There appears to be room for a considerable advance in wattmeter design with careful adaptation of this material. The introduction of iron into the main coil of a wattmeter has a similar effect to employing a current transformer with it, so that as some of these transformers are already satisfactory it should be equally possible to introduce the iron directly into wattmeters without causing appreciable error.

Induction Instruments

These instruments, which were principally originated by Ferraris, appeared in the first instance likely to become very popular owing to their simplicity, flexibility and robustness; and a very large variety of ammeters, voltmeters, wattmeters and frequency meters have been constructed on this principle; but it appears doubtful whether the type will finally persist for indicating instruments, although it will probably remain the standard type of

* *Journ. Scient. Insts.* November, 1925, p. 55.

alternating current electric meter, owing to its inherently rotational tendency. An induction instrument is essentially in principle a dynamometer instrument in which the current in the moving element is induced in it by an external alternating current magnet, instead of being conducted into it by springs or ligaments, and its behaviour is practically that of a dynamometer instrument fed by a P.D. or current transformer. The moving element of an indicating induction instrument therefore reduces to a simple disc or hollow cylinder, usually with spring control; while damping is provided by a permanent magnet acting on the same disc or cylinder, so that it is extremely simple and robust, and lends itself excellently to large angular displacements. These are very important advantages, but they are heavily offset by two disadvantages, (*a*) their inherently poor ratio of torque to moment of inertia, and (*b*) their high temperature variation.

The former difficulty arises from the fact that only a small portion of the moving disc or cylinder is at any time active in producing the torque, as the useful portions of these currents, *i.e.* the portions under the poles, are very small in comparison with the whole circuit and still smaller in proportion to the whole of the disc or cylinder, so that a very large amount of inactive metal is being rotated. As regards the temperature variation, since the moving element is nearly always made of aluminium as having the highest weight conductivity, the induced current and consequent deflection falls about ·4 per degree C. or practically by the same amount as in a voltmeter wound with copper wire, which is of course too high for any indicating instrument. If a low temperature coefficient alloy of fairly high mass conductivity could be obtained, this difficulty would be removed, but as practically all low temperature coefficient alloys have resistivities of 20 to 30 times or more that of pure metals, the reduction in torque would be too serious. Neither of these objections has any great force in the case of supply meters, as their nearly continuous motion renders the high inertia practically unobjectionable, and the increase of resistance of the moving element with temperature applies equally to the propelling and the braking torques, so that the speed is unaffected; but they are sufficiently serious to militate greatly against the production of accurate indicating instruments. It therefore seems unlikely that the induction type of indicating system will survive against the competition of the permanent magnet or soft-iron or dynamometer types, especially as they are of course unsuitable for direct currents, and are to a certain extent affected by frequency.

One type of instrument however which may perhaps be included in this category and which has various interesting features is that devised by Dr Sumpner in 1905. This instrument is in itself of the dynamometer type, having a coil into which current is fed through the springs or ligaments, but this coil is usually fed from what Dr Sumpner calls a quadrature transformer or iron-clad mutual inductance, so that this current is really induced from the primary winding of the transformer, and the whole arrangement is equivalent to an induction system in which the current in the moving element, instead of being directly induced in it, is led into it from an external inducing device. The moving coil is mounted in the field of a powerful laminated magnet wound with a coil which is connected to the A.C. mains, so that the field strength and the ratio of torque to inertia are large. The behaviour of this instrument is practically analogous to that of the ordinary induction system, but it is of course possible to reduce the temperature error to any extent by introducing manganin or other low temperature coefficient resistance between the secondary of the transformer and the moving coil, and it illustrates an interesting principle which formed the basis of Dr Sumpner's inception of it.

Regarding the magnet as practically a pure inductance L, we have $L\frac{\partial i_1}{\partial t} = V$, from which $i_1 = \frac{I}{L}\int V\partial t$, or the current in the magnet coil is proportional to the time integral of the

voltage. On the other hand, if M is the mutual induction of the quadrature transformer, and I the current in its primary, the secondary E.M.F. $e = M \frac{\partial I}{\partial t}$, and if R is the resistance of the whole secondary circuit including the moving coil, the current in it $i_2 = \frac{e}{R} = \frac{M}{R} \int V \partial t$. The torque in the moving coil is proportional to Ii_2 and therefore to $\frac{\partial I}{\partial t} \times \int V \partial t$, and since for a sinusoidal wave form $\frac{\partial I}{\partial t} = j\omega I$, and $\int V dt = \frac{1}{j\omega} V$, this $= I \times V$, so that the instrument reads as a wattmeter, and it can be shown that this is true irrespective of wave form. Obviously this principle does not hold universally for all frequencies in practice, as it is clear that no deflection will be obtained with direct current, but this is due to the resistance of the magnet coil which prevents the current in it from rising to infinity as the E.M.F. of the quadrature transformer falls to zero. For all frequencies in which the reactance of the magnet coil is large in comparison with its resistance, the law holds; although, unfortunately, the resistance still produces a phase displacement which requires a compensation as in other induction instruments. Fairly accurate wattmeters can be made for ordinary frequencies on this principle; and, in addition, the iron type of dynamometer is an extremely useful instrument for many testing purposes.

Thermal Instruments

Great advances have been made in these instruments since the inception of the original Cardew voltmeter in 1883, and in the latest form of "double sag" instruments, the principle of which seems to have been suggested by Profs. Ayrton and Perry but first put into commercial form by Messrs Hartman and Braun, they are still fairly popular, especially for high frequency measurements. It is to be doubted, however, whether instruments on the expansion principle are likely to survive for long against the competition of thermo-junction instruments. The low coefficient of expansion and high conductivity of metal wires demands a high temperature and a fine conductor, so that the heated wire is usually employed at nearly its elastic limit of tension and at a temperature which gives little margin for overload, with the result of a tendency to shift of zero and rupture by overload and by mechanical shock. The power consumption in ammeters of this class is sometimes not unduly high, being of the order of 1 to 2 watts, but in voltmeters for ordinary supply pressure it may be from 20 to 30 watts, on account of the external resistance required. In addition to this, expansion instruments are nearly always very sluggish in operation, taking in most cases 20 to 30 seconds to reach their final reading; and they are also subject to very troublesome temperature variations owing to the different coefficients of expansion and heat capacities of the hot wire and its supports, although various methods of compensation for this have been devised, with more or less successful results.

On the other hand, instruments on what may be called the cross-thermojunction principle, which has for many years been used by experimenters on radio measurements, have been recently developed in commercial form and seem to promise to be much more useful and effective. Within the last two years, the Weston Company have introduced a thermo-milliammeter of an extremely neat form consisting of an ordinary permanent magnet moving coil millivoltmeter with a small attachment in the base consisting of a short, slightly looped heating wire across which the thermojunction, presumably of copper and constantan, is soldered and connected to the moving coil. When 500 milliamperes is passed through the heating wire 14 millivolts are developed in the junction which is sufficient to deflect the moving coil to its full reading. The instrument has a much larger overload capacity than

any of the expansion instruments, and the thermojunction attachment is small, inexpensive, and easily replaceable.

A still bolder step in the same direction has recently been taken by Dr Moll of Utrecht University, whose work on sensitive thermojunctions is well known. He has applied these thermojunctions to commercial indicating instruments by producing what he calls a thermoconverter, in which a single straight heating wire is threaded or plaited through a series of 50 thermocouples and is mechanically in contact with them although insulated from them, and cemented so that no displacement is possible. The heating wire with a fuse in series with it has a resistance of 16 ohms and the thermocouple circuit of 18 ohms. When the heating wires carry 16 milliamperes the rise in temperature is less than 10° C. for an E.M.F. of about 8·5 millivolts which is sufficient for most measurements, but it may be loaded up to 300 milliamperes without injury. This type of thermoconverter has been put on the market by Messrs Kipp and Zonen, and may be used with millivoltmeters giving a full scale deflection for 60 milliamperes in the heating wire; and the application of this converter has been carried further to the production of thermal wattmeters on the well-known principle first put forward by Mr M. B. Field and used by Mr Irwin in his Hot Wire Oscillograph, *i.e.* of arranging two thermal elements in opposition—two ends of the heating wires being connected together through a non-inductive resistance to one main while the other two ends are connected to a low resistance interposed in the other main. In this way, he has succeeded in producing a very sensitive wattmeter which is suitable even for radio frequency measurements and should be of great utility.

Electrostatic Voltmeters

Electrostatic instruments have an enormous advantage over all electromagnetic ones in developing torque without continuous power consumption. Indeed, were it not for the extremely small forces available with apparatus of a reasonable size and with ordinary voltages, electrostatic instruments and mechanisms would certainly displace all others, even for heavy variable speed drives as in electric traction work; and if gaseous or liquid insulating media could be discovered having dielectric constants approximating to the permeability of iron, powerful electrostatic motors could be designed. Although no such media seem to be even in prospect at the present time; it may be well to call attention to this point in view of the extraordinary advances which have been made in other directions.

The start which Lord Kelvin made in his early electrostatic instruments was so excellent, that it was many years before any material improvement could be made upon them; but Professors Ayrton and Mather made an advance by the adoption of the quarter cylinder movement which had the advantage over the flat form of needle of enabling smaller clearances to be used with less risk of contact, and thus of giving us reasonably practical electrostatic voltmeters for ordinary supply or laboratory voltages. Since that time, the continued increase of high tension power supply has caused attention to be concentrated on electrostatic voltmeters up to hundreds of kilovolts, and here the series condenser principle suggested by Prof. Ayrton has proved most fertile; the majority of such voltmeters being of the type first introduced by Abrahamson, in which the voltmeter itself is of moderate range but is connected to one of a pair of plates, the other being connected to the high tension main. This device has proved very useful, as the range can easily be varied by altering the distance between the plates; but a large widely separated condenser is very liable to have its capacity altered by the proximity of other objects, and cases have been heard of in which the traversing of a crane has disturbed the calibration. By making the condenser with a curved plate nearly enveloping the voltmeter terminal, and by mounting it so as to be as clear as possible from the observer and other conductors, this effect has

been greatly reduced. On the other hand the parallel plate form of voltmeter based on the Kelvin electrostatic balance has been developed by Jona and his successors, and when properly screened has proved a useful instrument. Before mentioning the most recent developments attention may be called to the fundamental principle of the electrostatic voltmeter before mentioned, *i.e.* that the movement tends to increase the electrostatic energy of the system and that the torque $T = \frac{1}{2}V^2 \frac{\partial K}{\partial \theta}$. In designing it is simplest to work directly in electrostatic units, V being reckoned in electrostatic units of 300 volts and K in centimetres. The capacity of a condenser of uniform spacing between the plates $t = \frac{AK}{4\pi t}$ centimetres, where A is the area of the portion of the plates opposite each other, and K the dielectric constant of the medium, so that $\frac{\partial K}{\partial \theta} = \frac{K}{4\pi t}\frac{\partial A}{\partial \theta}$. If therefore the area increases uniformly with the angle, as is generally the case, $\frac{\partial A}{\partial \theta}$ is constant, and $T \propto V^2$, or the instrument has a pure square law scale if spring controlled. As a practical example of the use of this formula for design, suppose we require an electrostatic voltmeter for a maximum reading of 120 volts or ·4 electrostatic unit, and with a maximum torque T of 10 dyne cm. (·01 gr. cm.), Then $\frac{1}{2}V^2 \frac{\partial K}{\partial \theta} = \cdot 08 \frac{\partial K}{\partial \theta} = 10$ or $\frac{\partial K}{\partial \theta} = 125$ cm. per radian and will be constant if the instrument is to have a square law scale. For small clearance the dielectric strength of air may be taken as 30,000 volts per cm. so that the clearance need only be $\frac{120}{30{,}000}$ or ·004 cm., but it cannot easily be made less than ·03 cm., and since K is unity for air $\frac{\partial K}{\partial \theta} = \frac{I}{4\pi t}\frac{\partial A}{\partial \theta} = \frac{1}{\cdot 38}\frac{\partial A}{\partial \theta}$, so that $\frac{\partial A}{\partial \theta} = \cdot 38 \times 125 = 48$ sq. cm. per radian. If the system is either of the vane or quarter cylinder type with both surfaces active the area of the vane or cylinder enclosed between the fixed inductors on each side must increase by 48/4 or 12 sq. cm. per radian, so that for the quarter cylinder instrument the radius of the cylinder may be 2·5 cm. or 1″ and the axial length 5 cm. or 2″.

This example has been given to show the difficulty of producing a low reading electrostatic voltmeter, and the results correspond fairly closely with the actual data of the Ayrton-Mather voltmeters made by the Cambridge Instrument Company, which actually operate with a torque of about 10 dyne cm. But this torque is extremely small for a pivoted pointer instrument, and if the capacity could be greatly increased without enlarging the movement, the torque would be increased in proportion. So far as I am aware no one in this country has pointed out that the performance of such instruments might be greatly improved by immersing the system in oil or other liquid of high dielectric constant; which is all the more strange as an oil vessel with damping disc was used by Lord Kelvin in his multicellular voltmeters*. According to Kaye and Laby's tables methyl alcohol has a dielectric constant of 35, so that if the movement of an instrument of the above type were immersed in this liquid the torque would be increased to 350 dyne cm. for the 120 volts or the original torque of 10 dyne cm. would be obtained with a P.D. of $130/\sqrt{35}$ or about 20 volts. The liquid would have the further advantage of improving the damping, and of taking the weight off the pivots if a small hollow chamber were introduced into the movement. I am not sure that the insulation resistance of methyl alcohol is sufficient or if its dielectric

* Mr Paul has since informed me that he made experiments some years ago on oil filled electrometers, but that great difficulties were experienced with bubbles and convection currents. In view of the importance of the matter, however, it would seem desirable to explore every possibility of using liquid of high dielectric constant.

constant changes greatly with temperature, etc., but good insulating oils can be obtained with a dielectric constant of about 5, and it should be noted that this principle has already been adopted for high voltage instruments by the Westinghouse Company. It seems worthy of consideration for all electrostatic instruments. In high voltage instruments the gain is even much greater owing to the high dielectric strength of the oils employed, and although constants of such oils may be only about 5 instead of the 35 of methyl alcohol, the reduction of clearance rendered possible by their high electric strength enables the capacity to be increased in something like the same ratio. We may venture to anticipate therefore that considerable advances will be made in the future by the introduction of liquid filled movements, and it is to be hoped that it will stimulate research into the possibility of discovering or producing liquids of still higher dielectric constant and strength, for the improvement not only of electrostatic voltmeters but of vane condensers for radio work.

(*To be continued*)

NOTES UPON THE MECHANICAL DESIGN OF SOME INSTRUMENTS SHOWN AT THE EXHIBITION OF THE PHYSICAL AND OPTICAL SOCIETIES, 1927.

BY A. F. C. POLLARD, A.R.C.S., A.M.I.E.E., F.INST.P. Professor of Instrument Design at the Imperial College of Science.

(*Continued from p.* 190)

There can be no doubt that the judicious use of the hardened steel ball, which has been mass produced for so many years at a low cost with such remarkable accuracy as to diametral dimensions and sphericity, will considerably influence the design in the future of the lower pairs of turning and sliding in instruments where the relative rotation or rectilinear motion of two components is required with minimum variancy.

A nice piece of design of this type may be seen in the fine adjustment slide of the latest Leitz microscopes exhibited by Messrs Ogilvy and Co.

The slides of instruments generally consist of functional surfaces in sliding contact and are of the same type as those used in heavy machines, such as machine tools. Such surfaces must be fed with lubricant and though they may be in contact at some points during relative rest, immediately relative motion takes place these surfaces are separated by a film of liquid to the maximum extent of the necessary clearances in an indefinite manner. The motion therefore must be accompanied by marked variance and variable friction which at the commencement may reach high values. This is of no importance to machine tools, but renders the precise movements required by some instruments impossible to attain by these means and is responsible for much of the uncertain action of the fine adjustments of many microscopes. It is just this unsatisfactory action of their fine adjustment which determined Messrs Leitz of Wetzlar to design a ball-bearing slide.

The slide which is actuated by the well-known cam movement of this firm is shown in sectional detail in Fig. 7. The arrangement of the balls and ball races is shown in diagrammatic section in Fig. 8.

The moving hardened steel plate *III* attached to the microscope body is constrained to the single degree of freedom of sliding by four rows of four balls in each. The relative position of the balls in each row is shown in Fig. 7. The four races on the plate *III* are ground right-angled grooves and the two opposing races in the steel plate attached to the limb of

the microscope are a groove and plane respectively. The necessary pressure between these races and the contained balls is produced by the clamping screw *I* which forces the clamping plate *II* down upon the balls contained in the upper races of plate *III*. This clamping piece has two flat races and the action of the clamping screw is limited by the distance piece *V*.

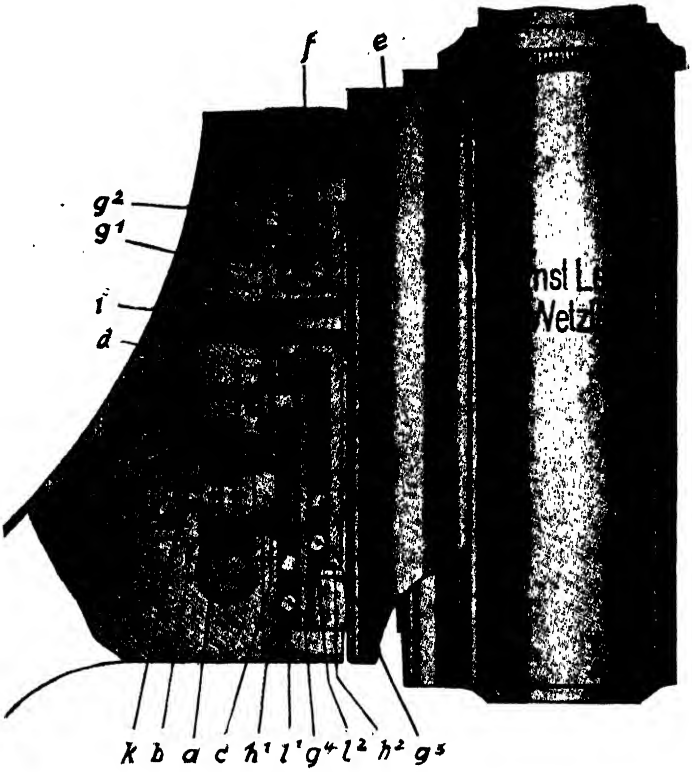


Fig. 7

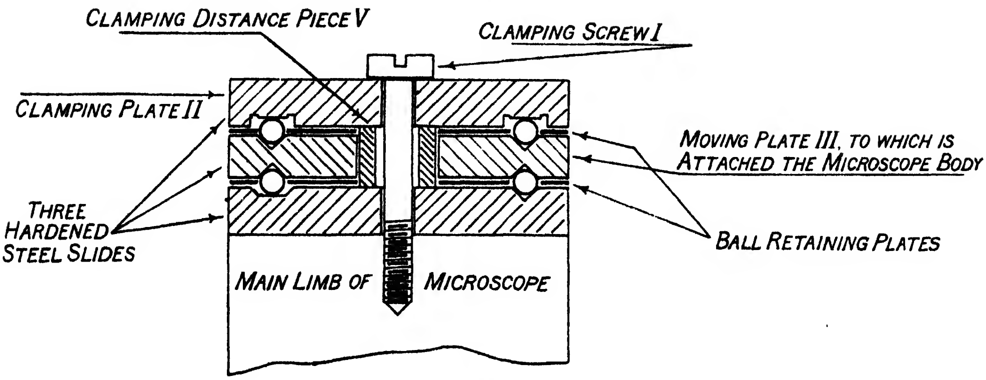


Fig. 8

The axial dimensions of this distance piece must have a specified tolerance so that the clamping pressure may lie within an upper and lower limit. It will be noted that the plate *III* is constrained in its motion parallel to the opposing lower right hand grooves, whereas the left hand lower flat permits the row of balls in the opposing groove to take up a position of repose. The function of the two upper grooves in plate *III* is merely to locate the rows of balls against the opposing flats on the clamping plate *II* which will not have any definite

position. Between these plates are placed two brass ball retaining plates with ample clearance. The balls loosely engage with holes in the brass plates and when the slide functions the plates move with half the speed of the microscope body. This slide functions in a manner which is unique.

One cannot help contrasting the *scientific* design of this slide (though from the point of view of economic manufacture the design might be improved) with the badly conceived optical bench of triangular section in common use. The slide of this bench consists of an elongated triangular prism of cast iron with the two upper surfaces machined to incline at an angle of 60° to one another. The brass saddles which slide on this prism and carry the optical fittings are V-shaped and it is expected that the inside surfaces of the V will accurately contact with the corresponding slide surfaces of the cast iron prism. Nothing of the sort ever happens except by the merest chance. A manufacturing tolerance is necessary both on the angle of the bench and on the angle of the saddle and no such tolerance can be permitted on one of these components, much less on both, if shake is to be avoided. It is impossible to make any accurate adjustment, such as the centring of an optical system on this bench, for directly the saddles are clamped they rock and everything is upset.

It is refreshing to find that Messrs P. J. Kipp and Zonen recognize the fact that this form of the optical bench is an impossible manufacturing proposition. In this firm's design of the bench which forms part of their Moll Microphotometer and Moll Nephelo- and Absorptiometer, the saddles carrying the fittings bear wholly on one surface of the cast iron slide only. The bearing on the other surface is taken by three adjusting screws tapped into the saddle.

The correct way to design this saddle however is to allow it to contact at three points on one surface and at two points on the other surface of the slide. The saddle is then left with one degree of freedom, *i.e.* sliding along the length of the bench, and if the last two points contact along a line parallel to the axis of the slide the saddle will automatically fit benches the angles of which differ not by a small manufacturing tolerance but by degrees.

Messrs Ogilvy exhibited a well designed Leitz Colorimeter and it is worth noting an apparently trivial point. The two components which carry the dipping glass rods slide vertically and their position can be read off vertical scales. To read these scales with ease and comfort a reflecting prism attached to each component and carried with it gives a horizontal image of the scale.

The same care is bestowed on the design of the Bio-Colorimeter exhibited by Messrs Gallenkamp and Co., the prism of the Leitz instrument being replaced by a mirror.

Clerk Maxwell laid down in 1876 five primary requisites common to all instruments and which he said are to be carefully considered in designing or selecting them. The primary requisite which has been so carefully fulfilled in the two instruments mentioned above is "that parts which have to be observed should not be covered up or kept in the dark."

It is a pity that some microscope manufacturers do not pay more attention to this axiom of Maxwell's and position the verniers of mechanical stages so that they are not covered up by the limb.

Messrs Ogilvy exhibited a standard millimeter divided into one hundred parts engraved upon a steel alloy for use on the metallurgical microscope stage. As this small but very important accessory is not mentioned in the catalogue of the Exhibition it was thought worth while to mention it here. Accurate micrometric standards for calibrating micrometer eyepieces are badly wanted by microscopists, who have not been over careful with the checking of their measurements in the past, and it is a sad fact that vast numbers of measurements of histological elements are valueless for this very reason. This is especially the case with the micro-organisms.

Amongst the exhibits of Messrs Cooke, Troughton and Simms there were many interesting

features. The cone centres of this firm's theodolites are scraped to as perfect a fit as can be obtained by skilled labour. The fitting of a functional curved surface whose principal radii differ to another similar surface is an expensive and tedious process but as every mechanician knows cannot be accomplished by lapping. The only surfaces which can be lapped are the plane, cylinder and sphere. The lapping of a cone by another cone will naturally enough produce deeper circular depressions in some parts of the conical surfaces than others, and the example of a lapped and scraped centre exhibited by this firm showed the defects of the former process in a very striking way. In spite of these obvious defects of lapped centres many manufacturers secure the fit of these components in this way.

The embedding of the abrasive in the surfaces is a very serious disadvantage in this method of manufacture.

When it is important to retain correct centring of the assembled O.G. with regard to the rest of the optical system, especially in theodolite telescopes to reduce collimation errors, the screw-thread ordinarily cut on the O.G. mounting is unreliable on account of the eccentricity of the threads. An improved design of this part of Messrs Cooke, Troughton and Simms telescopes is shown in section in Fig. 9.

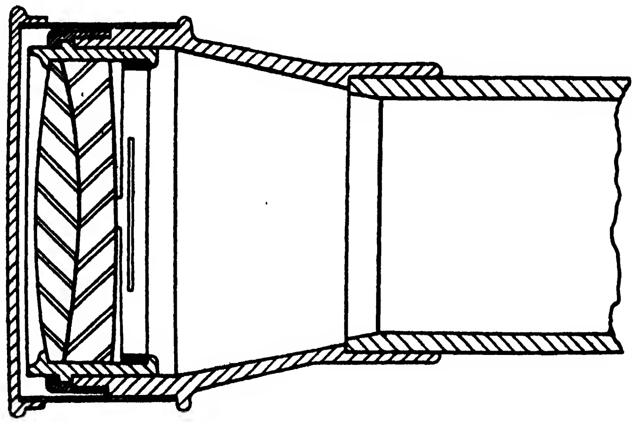


Fig. 9

The objective is accurately edged to fit its metal cell and is pressed at three points equidistant along its periphery against a recess by the washer shown in the figure. The washer is partially split circumferentially immediately below each contacting point so as to give the necessary spring. This metal cell is made plane externally to fit the end of the telescope tube with which it engages up to a shoulder and is kept in position by a clamping ring screwed to the tube. This construction ensures the replacement of the O.G. cell into the same position.

The illumination of theodolite circles and verniers is a matter to which this firm have given careful consideration. If light falls upon the engraved lines of the scales at different angles an error of several seconds may result. The shadow cast by the edge of the minute groove gives a false idea as to its true position and Messrs Cooke, Troughton and Simms overcome this source of error by simply illuminating the scales by diffused light which casts no shadows.

An ingeniously designed differential screw is to be seen on the Reversible Levels exhibited by this firm. A section and side elevation of the metrical fine adjustment to the tilt of the telescope is shown in Fig. 10.

Since the ultimate movement is the difference of the pitches of the two screw spindles for one turn, the threads have to be cut with great accuracy, but if this can be done success-

fully the mechanism is a beautiful one. Unfortunately space forbids the description of many recent and interesting developments in design by this firm.

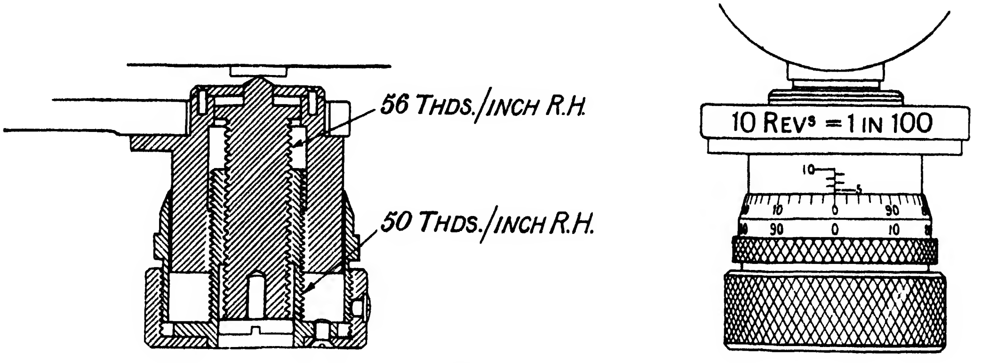


Fig. 10

Some very robust and well made apparatus manufactured by Messrs R. W. Munro, Ltd. was shown by Messsrs The Laboratory Equipment Company. Special attention is directed to the excellently designed Denne Variable Light Filter obviously thought out by an engineer. The Filter is shown in Fig. 11.

The cell which contains the dye solution, fed from a small reservoir, is closed by two parallel glass plates. One plate is fixed to the main casting but the other forms the base of a piston which can be made to slide and thus vary the thickness of the solution on the principle of the Berger fine adjustment by turning the milled head seen on the left.

Some well designed Microtomes of considerable rigidity with other apparatus were exhibited, but it was much regretted that the Large Model Microscope with Floor Pedestal designed on the most novel lines and containing many interesting details, also designed by Mr M. F. Denne, was not on view.

The exhibit of the series of Zeiss Fine Measuring Instruments by Messrs Dowdings' Machine Tool Co. Ltd. was of considerable interest but so extensive that a separate description will have to be reserved for future pages of the *Journal*.

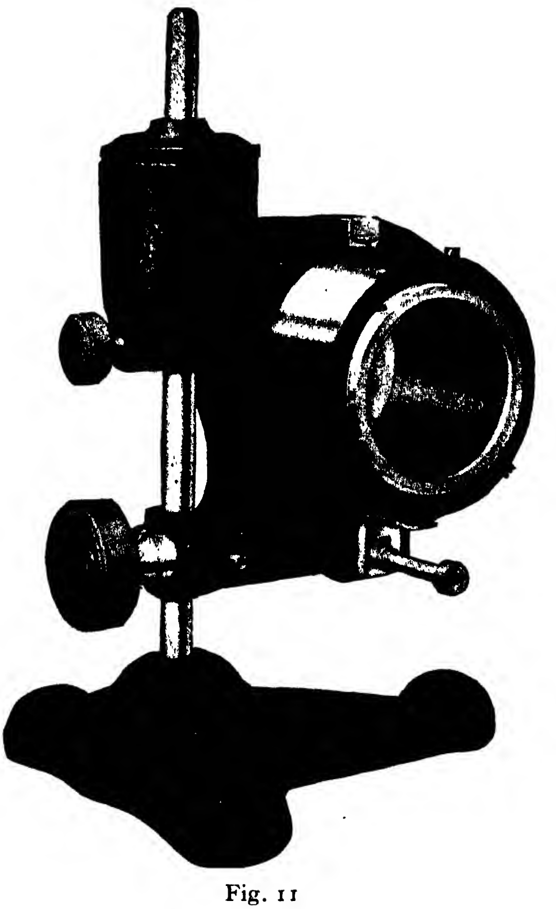


Fig. 11

It is quite impossible to do justice to the many interesting details of mechanical design which were to be seen at the Exhibition, but those selected show the change which is slowly taking place from the heavy engineering type of design exhibiting marked variance and other instrumental imperfections to the more enlightened type of design which reduces these undesirable features to an absolute minimum, as well as the number of limit or functional gauges used for the purposes of manufacture.

In conclusion attention is directed to the exhibit of Stainless Steels by Messrs Thos. Firth and Sons, Ltd. These steels are an invaluable material for the construction of many parts of instruments. It would appear that misconceptions on the difficulty of working and machining these steels is responsible for their limited use.

Messrs Firth manufacture three forms of stainless steel containing 12–14 per cent. of Chromium and their latest stainless steel "Staybrite" contains 18Cr 8Ni.

The stainless steels are distinguished as F.H., F.G., F.M. and F.I. in order of descending C content. The F.M. or F.I. steels are similar to mild steel, can be easily forged and machined and require no heat treatment after forging. The F.G. steel of about 50 tons is sent out heat treated and in machinable condition. After machining it requires no further heat treatment. But the F.H., a high tensile steel which can be tempered and is useful where maximum hardness and maximum tensile strength is required, loses its non-corrosive properties in the annealed condition. It is similar to 0·9 C steel in its magnetic permeability.

"Staybrite" however is non-corrosive in all conditions. It can be annealed at a temperature of 1000–1200° C. and is then extraordinarily ductile and non-magnetic, but immediately it is cold-worked its hardness rises to a very high value, it cannot be easily forged or machined and it becomes slightly magnetic. So readily does this material harden when cold-worked that particular care must be taken to see that cutting tools are really cutting and not cold-working the material. For example if high speed drills with power behind them are not used for holes, the drill point tends to cold-work a hard spot which can only be removed by heat treatment.

The stainless steels can be readily distinguished from "Staybrite" in the annealed condition by their magnetic properties.

(*Concluded*)

A TILTING FRICTION MACHINE. By P. E. SHAW, M.A., D.Sc., F.Inst.P. University College, Nottingham.

[*MS. received*, 8*th July*, 1926, *and amended* 31*st December*, 1926.]

ABSTRACT. The apparatus is an improved form of one described by the author and C. S. Jex (*Proc. Roy. Soc.* A, III, June 1926) for measuring the coefficient of friction of solid rods as the surfaces of these are prepared in various ways. Instead of observing, as is usual, the tangential and normal stresses for statical friction, the table carrying the rods is tilted until sliding occurs at a critical angle, θ.

The peculiar features of the device are: (*a*) the maintaining of identical rubbing parts as the table is tilted repeatedly to one side and then to the other; the rods being guided by stops so as to have only one degree of freedom; and not being handled throughout the whole series of rubs; (*b*) the upper sliding rod supported equally by the lower one (which is rubbed) and by a thread; (*c*) using *rods*, it is possible to experiment on a great variety of commercial or prepared material, and to clean or otherwise treat the surfaces very thoroughly.

In use the apparatus works quickly and reliably, and for some purposes, *e.g.* for friction work *in vacuo*, should prove invaluable.

Apparatus

At the upper end of the photograph (Fig. 1) is seen a horizontal table supporting two rods, each $5\frac{1}{2}$ in. long. The lower one rests on two V's, and is held firm at the near end by a band spring. The upper rod rests on and perpendicular to the lower one and is supported at a like distance from the right end by a bifilar suspension of cotton, whose ends are attached to the horizontal bar on the upright pillar. The special purpose of the left-hand pillar will be noted presently.

The horizontal table is attached to the index arm seen in the front of the apparatus. Table and arm rotate together on a horizontal axis perpendicular to the plane of the circular scale shown. When adjustments are made by the levelling screws the circle lies approximately in a vertical plane.

On moving the arm to right or left the critical angle of friction, θ, is reached and the upper rod slides on the lower through a small range, about 2 mm., between stops at each end.

Since the sliding rod is supported equally by the lower rod and by the cotton, the coefficient of friction (μ) is given by the equation

$$\mu = 2 \tan \theta.$$

This relation is precise if the rod is uniform and the supporting points symmetrical with respect to the ends; and the error arising through lack of symmetry when sliding commences does not concern the statical friction which we are observing.

By taking scale readings to right and to left we obtain angle Θ between the two, then:

$$\mu = 2 \tan \frac{\Theta}{2}.$$

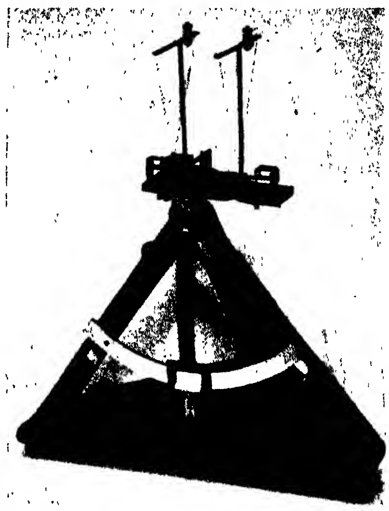


Fig. 1. The tilting friction machine

By this method it is clearly unnecessary to know the exact angle at which the sliding rod is horizontal.

In practice, the index arm is not touched by hand during an experiment: a cord, attached to the handle seen below the index arm, passes to right and to left over pulleys (not shown) and thence to weights, say 100 gm., hanging vertically. On raising or lowering one of the two weights a smooth rotation is given to the moving system.

The best way to operate is to incline the lower rod so that the sliding rod rests slightly against two guiding bars. In this way we ensure that as the rod slides to and fro the upper and lower rods are rubbed always *at the same places*. This is an important condition to fulfil, since the frictional qualities of solid surfaces vary greatly from point to point and our concern is with the friction at one definite place.

But, since the sliding bar touches these guides, there is some small friction on that account. To measure this, the left-hand bifilar is employed: the lower rod is removed and the upper one is supported by the bifilar at each end. The tilting process to right and left is again performed and the doubled critical angle ϕ is found. This is small, say 2°. Then we have the equation

$$\mu = \frac{2\left(\sin\frac{\Theta}{2} - \sin\frac{\phi}{2}\right)}{\cos\frac{\Theta}{2}}.$$

It is necessary to adjust the upper rod so that the vertical plane in which it lies is perpendicular to the axis of rotation of the table.

Preparation of the Surfaces

We have used rods of glass, vitrious silica and brass; but clearly a great variety of material in rod or tube form is at the disposal of the experimenter. The rods before use are cleaned thoroughly by solvents in test-tubes. Glass and silica are boiled in chromic acid; brass is treated with nitric acid. The length of time given to the cleansing is found to affect the

result. In the case of glass the roughening process is rapid at first but continues to increase only very slightly after twenty minutes' boiling.

After the action of the acid or other solvent, the rod is removed from the test-tube by tongs, which have been cleansed of all grease, etc. by treatment in a bunsen flame. Prolonged washing at the tap is followed by boiling in distilled water.

On removing the rods from this last bath the water evaporates rapidly and the rods are placed dry in position on the apparatus, and tested at once for friction. During the above processes the rods never touch the hands or any other contaminating bodies.

Advantages of the Method

(1) A feature of the tilting method is its ease and quickness in action.

(2) The rod form of solid is easy to clean; it gives the investigator a great range of material, metallic or non-metallic, whether in tube or solid form; and it is possible to investigate the friction at known places since rubbing occurs along definite generating lines and at definite spots.

(3) A direct cause of inaccuracy in any measurement of friction is vibration; this imparted to the system tends to reduce μ by prematurely starting the sliding of the upper solid. The present method of tilting can be made very smooth, probably more so than the usual one in which additional load is continuously added to a pan.

Experiments on friction are best performed *in vacuo*, or at least in a closed chamber in which the atmosphere can be varied and controlled at will. The tilting method is self-contained and should therefore be more easy to use in a vacuum than the discontinuous method of additional loading.

Examples. The paper already quoted gives some details not mentioned in this article. It also has some curves illustrating the changes which occur in the friction of *glass* as it is (*a*) cleaned, (*b*) rubbed with fabrics, or (*c*) left in the air. Two other examples are given:

I. The following table and curve (Fig. 2) show the corresponding (and in most respects, the like) effects for *brass*.

Table. *Results for the coefficient of friction of brass on brass*

		μ mean value
A	Two brass rods wiped by duster	·30
b	Dipped in dilute nitric acid, washed, dried	·40
c	Dipped in strong nitric acid, washed, dried	1·00
D	Dipped in strong nitric acid, again washed, dried	1·20
e	Left in the air for 1 hour	1·10
f	Left in the air for 12 hours	·88
g	Left in the air for 48 hours	·52
H	Left in the air for 1 week	·44
D′	Dipped in strong nitric acid, washed, dried	1·17
α	Rods at stage *b* on graph burnished by rubbing together in air	·28
β	Rods at stage *b* on graph burnished by rubbing under water...	·36
γ	Rods at stage *D* burnished by rubbing together in air ...	·44
δ	Rods at stage *D* burnished by rubbing together under water...	·52

Point *A* gives the value of μ for the rods as taken from stock and wiped free of dust. The friction rises after cleansing and increases as the action of the acid continues at points *b*, *c* and *D*. Degeneration of μ due to adsorbed vapours sets in when the clean rods are left in air. This is shown in points *e*, *f*, *g*, *H* and the acid again brings up friction to point *D′*.

Coefficient of friction, μ, for brass rods

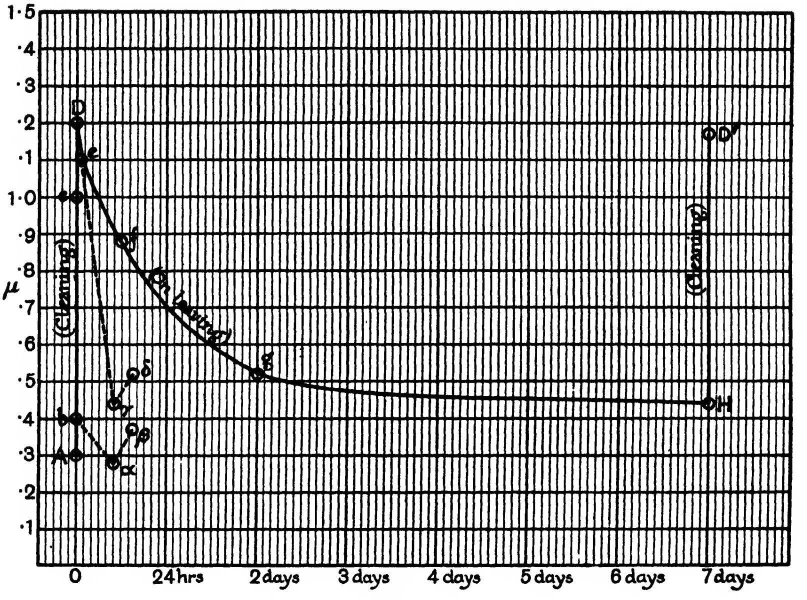


Fig. 2

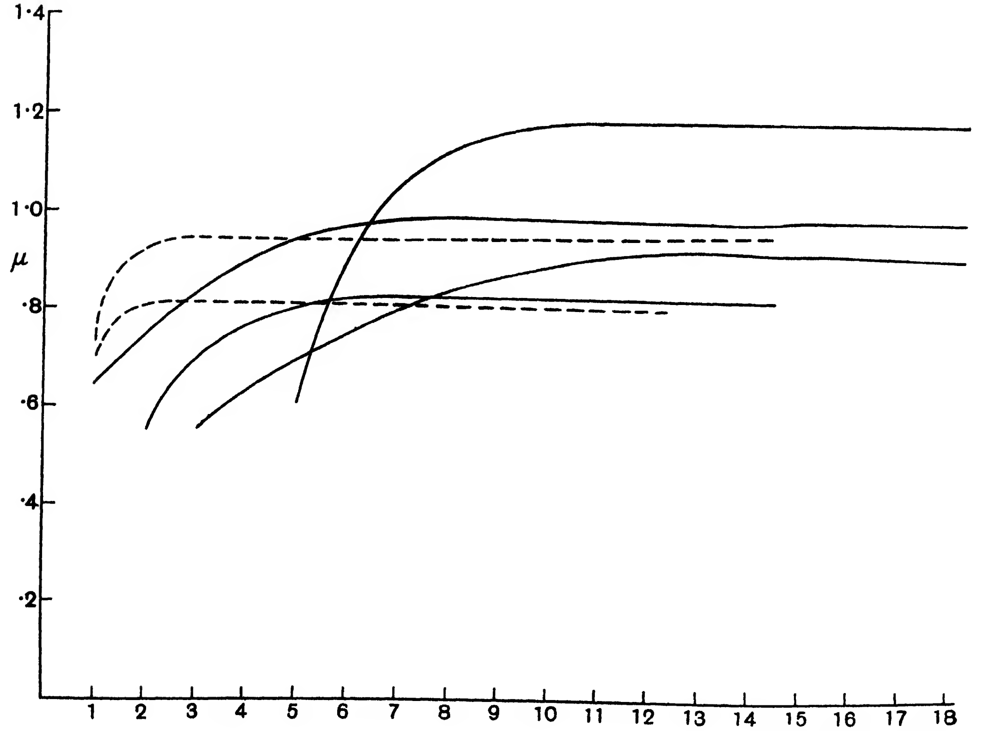


Fig. 3. The effect on μ of repeated rubbing of glass rods on the tilting machine

Another treatment of the brass rods is to burnish by rubbing them together in air or in water. When the rods are uncleaned we get values as at α, β; when cleaned the values are higher as at γ, δ.

The terminal and most interesting points, A, D, H, are emphasized by being in capitals. It may be observed that the same behaviour as to friction is found for glass as for brass. Further investigation will probably show that these effects are general, but vary in degree with all solids.

The method described above, being simple and instructive, makes a useful laboratory experiment. I am indebted to two junior students, Messrs D. Jenkinson and G. H. Perry, for the results in the table given.

II. The operation of obtaining μ is quick, and can be repeated as often as desired. The curves (Fig. 3) show the effect on μ of repeated rubs on *glass*. There are two cases:

(1) (Dotted curves) recently cleaned surfaces require at most one or two rubs to bring up the full and final value of μ.

(2) (Full curves) rods left for many hours in the air, have initial value of μ small; but μ increases as the rubs are repeated and after much friction settles asymptotically to a final high value.

These curves cannot be interpreted, with any assurance, without further detailed investigation, with change of experimental factors: for, not only is the adsorbed layer rubbed aside at each stroke, but in addition the *solid* surfaces themselves are abraded more and more at each rub and we have the changed conditions associated with the Beilby "flow."

The field of friction between solids is clearly a *terra incognita*.

THE QUADRANT ELECTROMETER.

By JOHN F. SUTTON, B.Sc. (Eng.)

[*MS. received, 6th January,* 1927.]

ABSTRACT. The paper is intended to be an analysis of the principles involved in the practical design of the quadrant electrometer with special reference to its use as a wattmeter for calibration purposes.

It indicates briefly the advantages of the electrostatic method for the measurement of power, and refers to the extreme difficulty experienced in manipulating the early types of instrument.

A description is given of the chief points in the design of the Standard Electrometer constructed at the Reichsanstalt in 1907, and reference is made to the instrument installed at the N.P.L. in 1912.

A list is given of the conditions which are essential to the design of an instrument having a straight line law, and a criticism of some of the devices which have been adopted to conform to these requirements.

In conclusion, a design is given of an instrument suitable for commercial purposes which can be constructed in such a manner as to ensure the maximum degree of accuracy and to provide the minimum number of adjustments.

It is probable that the Quadrant Electrometer arranged as a wattmeter would have entirely displaced the dynamometer type of instrument to-day as a standard for calibration purposes had it not been for the extreme difficulty experienced in manipulating the early types of electrostatic instrument.

This difficulty has been completely overcome by designing the instrument so that it can be constructed with accuracy and adjusted easily without causing too much disturb-

ance to the moving system. An instrument of good design is found to be as simple and rapid in use as a moving coil galvanometer.

The electrostatic method for the measurement of power has several advantages over the dynamometer method, the chief ones for calibration being:

(*a*) A single instrument may be used for currents and voltages of any magnitude.

(*b*) The current taken by the pressure circuit is exceedingly small, being for normal frequencies less than one micro-ampere.

(*c*) The instrument has no frequency error.

(*d*) Its sensitivity can be increased many times when it is used for measurements at very low power factors by increasing the voltage drop across the quadrants.

(*e*) If desirable it can be used as a zero instrument to avoid calibration errors.

Its chief disadvantage is that the deflectional torque is exceedingly small, necessitating a delicate suspension. It must be protected from draughts, dust, and vibration, and is not portable. These conditions can easily be observed in a laboratory. Although the electrostatic method was first investigated by Ayrton and later by Addenbrooke in 1900, the instruments which the latter used were of rather a crude nature, judging by the illustrations of them, and it is probable that the first electrometer designed and constructed upon rational lines was set up at the Physikalisch-Technischen Reichsanstalt and described in *Zeitschrift für Instrumentenkunde*, **27**, 1907, p. 65.

In this instrument every part of the electrical system was made adjustable by a micrometric method. A skeleton diagram showing the arrangement of the various parts is given in Fig. 1. The base is a circular brass ring *a*, mounted on three ebonite pillars with levelling screws. On this is another concentric ring *b* carrying three pillars, and on the top of these is the upper portion of the instrument. The whole quadrant system is adjustable relatively to the base by three levelling screws *c* having divided heads and scales. Each set of quadrants is mounted on a base, the bottom set to *d* and the top set to *e*. Plates *d* and *e* are adjustable relatively to one another (for varying the distance between the quadrants) by three more levelling screws with divided heads and scales *f*. The plates *a*, *b*, *d* and *e* are all accurately constructed and mounted co-axially so that there is no necessity for relative axial adjustment. The plate *g* on top of the main pillars has a flange turned on it, and the tube *h* carrying the suspension and mounted on a framework *k*, *l* can be adjusted axially by three equidistant radial screws. This adjustment is provided so that the suspension can be brought into line with the axis of the quadrant system without disturbing the levelling screws at the base.

The suspension itself is attached at the top to a rod which is capable of vertical and rotational adjustment so as to bring the needle to the correct position relative to the quadrants. An air damper *m* is provided underneath the base, and of course the two plates of this are provided with vertical adjustment. Reference will subsequently be made to details of construction of this instrument.

The next instrument which marked an advance in design was that constructed at the National Physical Laboratory and described in the *Journal I.E.E.* **51**, 1913, p. 294. The advance in this case consisted in a simplification of some of the details of construction—notably the method of attaching the quadrants to their base and the removal of the damping vane and its adjuncts. The latter alteration was rendered possible by a novel construction of the needle, much reducing its moment of inertia and making it possible to obtain sufficient damping from the air friction between needle and quadrants.

The wattmeter which is now in use in the Electrical Measurements Laboratory of the City and Guilds Engineering College was constructed upon similar lines to the N.P.L. instrument and is illustrated in Fig. 2. A few of the details were altered when the drawings

of the instrument were prepared. Various difficulties which arose during the construction and adjustment of this instrument have shown that the design might with advantage be still further simplified. Fig. 3 illustrates the essential parts of an electrostatic wattmeter and the connexions for measuring the power supplied to a circuit.

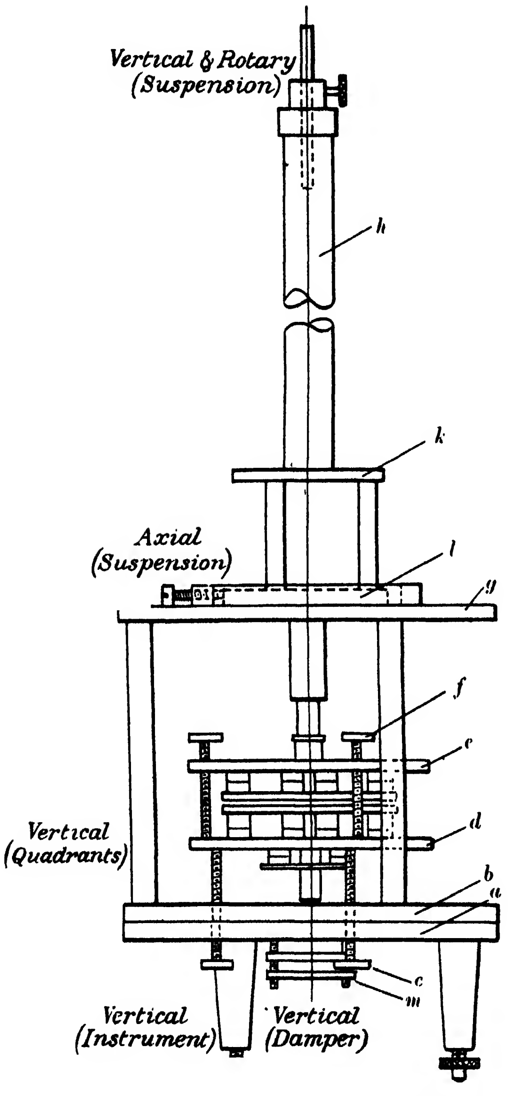


Fig. 1. Skeleton diagram of Reichsanstalt Instrument showing various adjustments

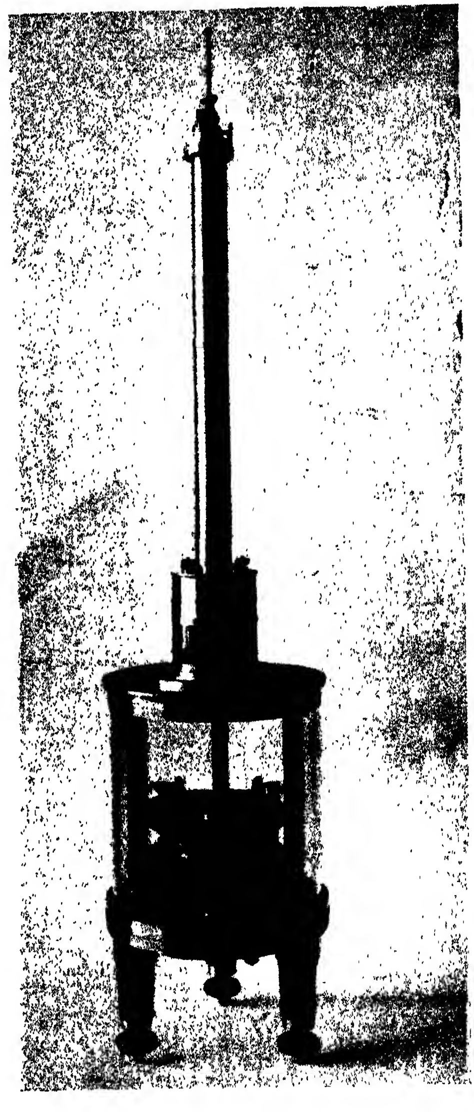


Fig. 2

It is proposed to suggest in what follows a method of construction in which accuracy is obtained with expenditure of less mechanical skill than that needed in the previous instruments, and which also enables the setting up and adjustment of the instrument to be a simple and rapid process.

In the construction of an instrument certain inaccuracies are inevitable, but they may be so small that they can only be discovered by electrical means when the instrument is set up. Therefore provision must be made to counteract the effect of these inaccuracies by special

adjustments. In the case of the electrometer, in order to ensure that the deflection shall be accurately proportional to the applied voltages it is necessary that

(*a*) The quadrant surfaces should be flat, co-axial and uniformly conducting.

(*b*) The needle should be flat and accurate in outline, and should move in a plane parallel to the quadrants.

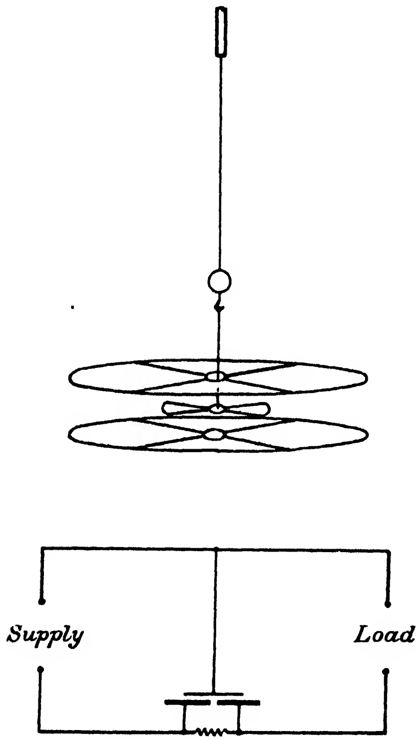


Fig. 3

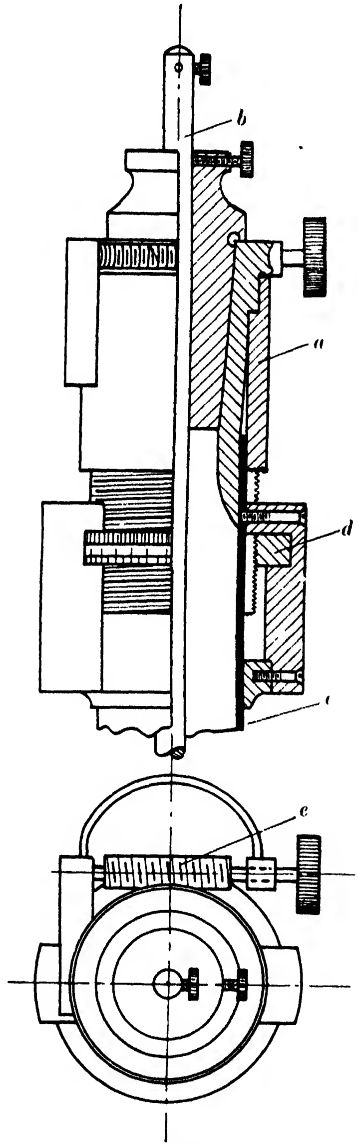


Fig. 4. Suspension fitting on Reichsanstalt Instrument

(*c*) The axis of rotation of the needle should pass through the centre points of the quadrant surfaces.

(*d*) The plane of the needle should be midway between the quadrant surfaces.

The importance of these points increases rapidly as the vertical distance between quadrants is reduced, in the endeavour to obtain the highest possible sensitivity. Condition (*a*) can be fulfilled sufficiently by careful design and construction; the quadrant surfaces, being

gilded if necessary. Adjustment is not essential. The second part of condition (*b*) and condition (*c*) can be obtained with two adjustments only; tilting the whole instrument on its levelling screws until the needle is co-axial with the quadrants, and then adjusting the level of the quadrant system. This final adjustment can only be carried out when the instrument is connected to a source of supply, A.C. or D.C., with all the quadrants connected together and at a potential of about 100 volts with respect to the needle and case. The level of the quadrants is altered until no deflection of the needle occurs when the supply is switched on or off. The position of the needle when a potential difference exists between itself and all the quadrants connected together is called the *electrical zero*, and in a well-made instrument very little final adjustment is needed to make it coincide with the mechanical zero.

The parts of the instrument which need most consideration in design are (1) the quadrant system, (2) the suspension fitting, and (3) the suspension itself. In the suspension fitting it is necessary that the needle should be capable of coarse and micrometric vertical adjustment, and independent rotary adjustment. Fig. 4 shows approximately the construction

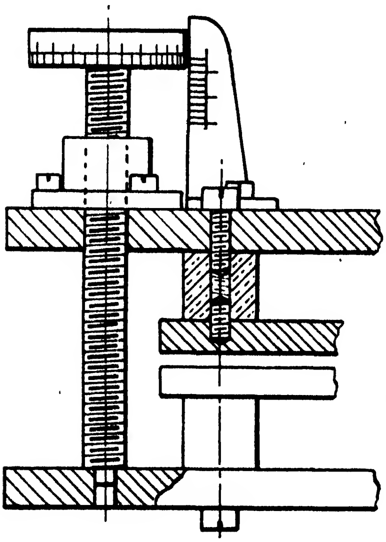


Fig. 5

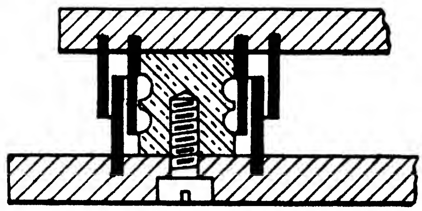


Fig. 6

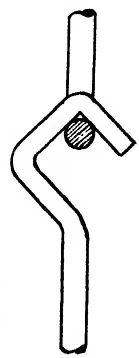


Fig. 7

used in the German instrument. Actually it is rather more complicated than the diagram given, but this is sufficient to show that although its performance may be ideal, it is far too complicated to use in a commercial instrument. (*a*) represents a slotted brass sleeve to give vertical movement without rotation, and (*d*) is the micrometer nut fitted to it; (*e*) is a worm driven rotary adjustment, and the suspension is attached to the rod (*b*) which can be moved up and down, or rotated for coarse adjustment. The construction adopted for the City and Guilds instrument is shown in Fig. 8, and it has been found to work perfectly. It is necessary to have the radial adjusting screw an easy fit or the force necessary to turn it will set the needle in vibration.

The quadrant system shown in Figs. 1 and 6 might be simplified with advantage. It consists of two circular brass disks, each one having four quadrants mounted co-axially upon it. The bottom disk rests on the points of three adjusting screws whose nuts are fixed to the base, and the top disk has three similar adjusting screws whose points rest upon the upper surface of the bottom disk. Thus, in addition to providing vertical adjustment, the screws must be made to serve the purpose of keeping the quadrants co-axial with each other and with the axis of the instrument. In the N.P.L. instrument the hole, slot, and plane

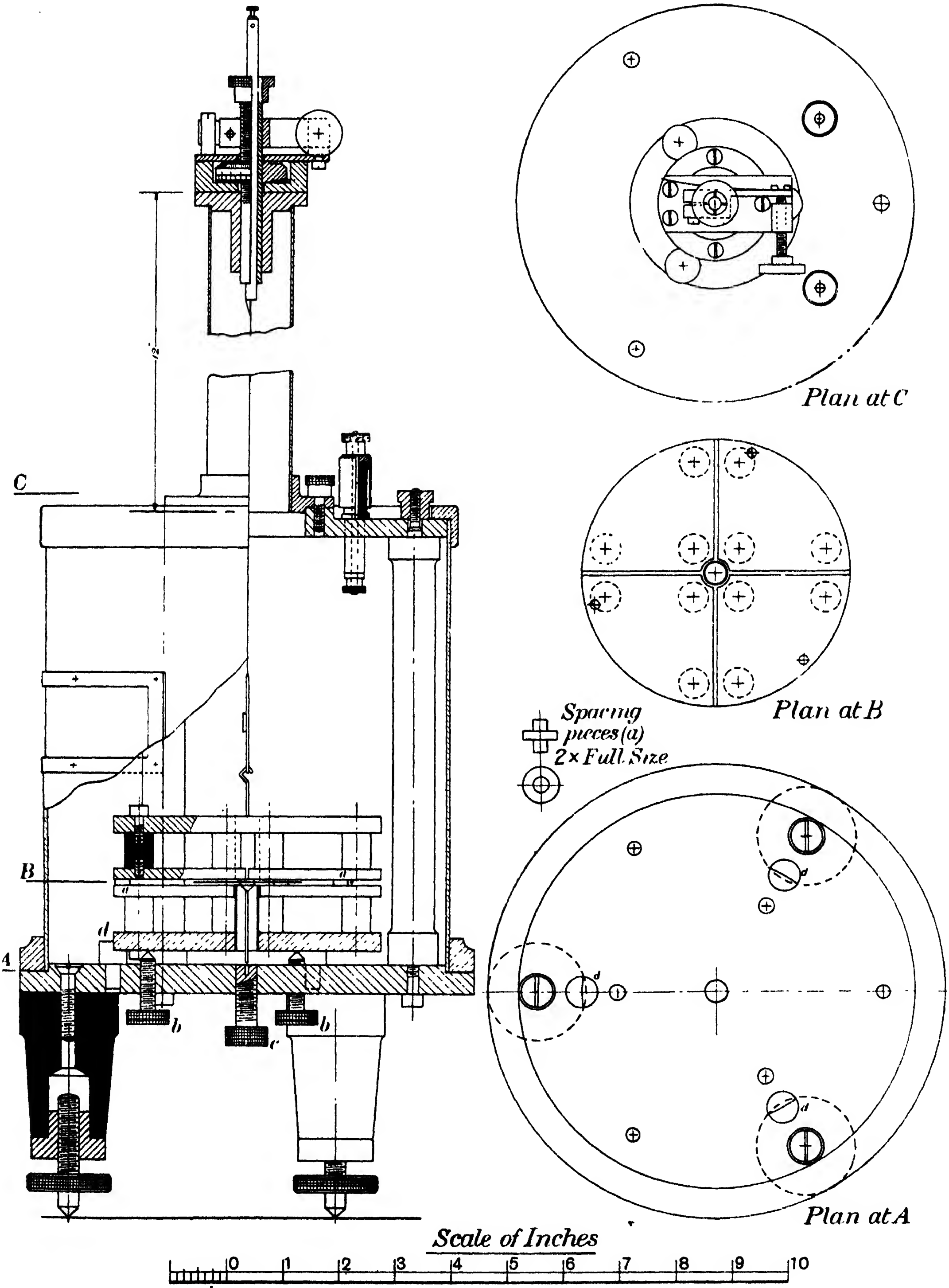

Plan at C
C
12"
Plan at B
Spacing pieces (a) 2 × Full Size
B
d
A
b
c
b
Plan at A
Scale of Inches
0
1
2
3
4
5
6
7
8
9
10

Fig. 8

device was used for keeping the disks central, but this is very difficult to mark out and machine accurately, and the slightest irregularity or looseness of the adjusting screw which fits in the hole or slot will cause the disk to move horizontally. An easier and more accurate method is to mark out the two disks together and drill three small holes right through both of them. The holes in the upper disk are then bored out to clear the screw threads and the points of the screws have shoulders which fit over the hole in the lower disk (Fig. 5). With this construction horizontal movement is more restricted since the effect of any irregularity in one screw is reduced by the stability of the others.

Experience has shown that combined distance and locating pieces between the quadrants themselves would be just as good as adjusting screws and would simplify the construction; and for tilting the quadrant system to make the electrical zero coincide with the mechanical zero the arrangement shown in Fig. 8 should be quite satisfactory. The three pegs (*d*) which serve as guides and supports for the bottom disk are driven into the base plate and the slots are turned concentric with it. Tilting is accomplished by means of the screws (*b*) which are thus relieved of a purpose for which they are fundamentally unsuitable—namely, that of keeping the bottom disk concentric with the base. The screw (*c*) is in the centre of the base and is used for taking the weight of the suspension if the instrument is moved and also for centring the needle when setting up the instrument.

The little pillars supporting the quadrants may be made of best quality ebonite if the instrument has a brass case to keep the light from them. It is essential that they are all of exactly the same height and that the tapped holes at each end are co-axial. Fig. 6 shows the construction used in the German instrument. The insulation is ebonite and the object of the shields is stated to be "to prevent any disturbing action of the insulation on the suspension or the needle." They appear to be an unnecessary refinement as the suspension is shielded by the tubes which surround it and which are at the same potential.

It simplifies the construction somewhat to arrange the upper part of the instrument as Fig. 8 instead of mounting the suspension tube on three pillars. The window for the mirror can be made of clear mica.

With regard to the suspension, it is essential that all the parts be made as light as possible, not only to keep down the moment of inertia, but also to reduce the direct stress in the suspension fibre to the minimum. The hook of the needle should be filed to the shape indicated in Fig. 8 to avoid back lash.

The first suspension used on the City and Guilds instrument was phosphor bronze strip $0{\cdot}006'' \times 0{\cdot}0002''$ in cross-section. At unity power factor full scale deflection ($\frac{1}{3}$ radian) was obtained with 100 volts on the needle and 0·2 volt between the quadrants, the latter being $2\frac{1}{2}$ mms. apart, but the zero reading was very unsteady. This was accounted for by the fact that the direct stress in the material was about 5,500 lbs. per sq. inch or nearly equal to the elastic limit. The shear stress due to torsion is quite small and would certainly not be sufficient to cause fatigue. A suitable cross-section to give sufficient sensitivity for most purposes and yet retain a steady zero would be about $0{\cdot}010'' \times 0{\cdot}0004''$. A long suspension is likely to be more satisfactory than a short one as the cross-section can be kept fairly large for a given sensitivity and the direct stress thereby reduced.

LABORATORY AND WORKSHOP NOTES

THE MICROSCOPE IN THE WORKSHOP. By B. BROWN, B.Sc. (Eng.).

[*Received 29th November*, 1926.]

The microscope which is employed so extensively throughout science, has but a limited application in the modern engineering factory. Where it is used it is for metallographic purposes alone. It seems somewhat strange that so useful a tool is so badly neglected by those who have most need of its help.

There are signs that we are about to enter a period when optical methods of measurement will play an important part in production work. We understand that the undoubted merit of such apparatus is gradually modifying the practical engineer's distrust of things pertaining to the scientific.

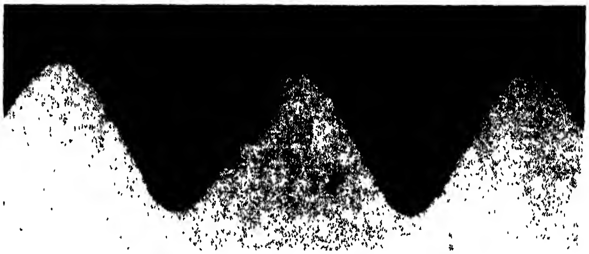


Fig. 1. 8 B.A. plug gauge. Bad form

Fig. 2. 8 B.A. plug gauge. Good form

The optical projector has been in general use for gauge making for several years, though there are a number of firms yet who cannot or will not see the great advantages which are to be derived from its adoption.

The projector has several advantages over the microscope for shop use. There is less eyestrain, less chance of distortion since magnification takes place chiefly owing to the distance from the screen, and the image possesses definite size independent of the human eye. Nevertheless, there are some ways in which the microscope is the more satisfactory tool. Chief among these is the readiness with which a photograph can be taken. There sometimes arise cases where it is useful to compare parts at different stages in manufacture. With the ordinary type of projector this is difficult since no copy can be made.

Recently the writer was engaged in an investigation of the means of producing thread gauges. No projector being available, he requisitioned a photomicrographical set. Examination was made by using a powerful illuminant in the form of a "projector" lamp to throw

the shadow image upon a sheet of white card placed normal to the optical axis of the arrangement. The eyepiece was left in position so that the image was kept close to the instrument. This was a decided advantage, since when one is handling pieces in the strong light the eyes are not in a fit state to observe things at a distance. For the smaller work a ⅔ inch objective was used. This gave a magnification in the region of 130.

Permanent records of important examples were made by use of the camera. No plates were used, the reproduction being made direct upon bromide paper. Naturally the results were inverted as regards light and shade but this was no disadvantage. A commercial form of sensitive paper was used, such as is employed in some of the types of copying machines. The whole process, from its cheapness and rapidity, should commend itself to the commercial user.

Figs. 1 and 2 show examples of the results reduced to half size. The former is of a badly formed thread and the latter of a good one. Both represent 8 B.A. and the magnification was 140. This latter relation was found by checking up a standard wire on the ground glass screen of the camera. It will be appreciated that as the photographs represent threads on

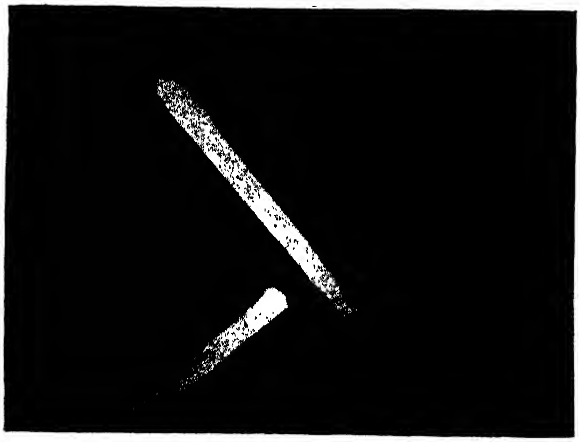


Fig. 3. Fused filament of valve

plug gauges taken by transmitted light, the actual gauges will appear as white when the paper on which they are taken is a negative printing one.

Fig. 3 shows the ends of a fused valve filament to approximately the same magnification as before. Those interested in this work will note the difference in ends due, possibly, to the difference in polarity.

One further point may be mentioned with regard to the use of bromide paper for taking direct prints, and that is that no dark room is required. If the blinds be drawn and the paper developed face downwards quite good results are obtained. Those illustrated are none too good, since the paper used was old and had become slightly fogged.

ERRORS IN LEVELLING STAVES

EVERY wooden levelling staff, papered with inked divisions, is liable to expansion and contraction, variable with the atmospheric alterations. It is found that the P.E. is as much as 0·006 ft. This is a very large and grave error viewed from a careful leveller's eye and experience, and a correction of the error should be made to the results obtained to enable

a sound "closing" result being determined. The best method is to "standardize" the staff with an "Invar" standard tape—having little or no error. Lay the staff on a flat bed face upwards and stretch the Invar tape over the front, the tape being attached to a micrometer wheel at one end, and an 8 lb. weight at the other, the "bed" being off the ground. Set the micrometer at zero and the graduated tape end of divisions at extreme end or shoe of staff, the tape of course being marked at feet-tenths-hundredths of feet. The error at every foot or less is obtained by moving the micrometer until division of the invar tape coincides with staff division. A chart or curve is then plotted and the error at every foot obtained ready for observations.

"PRECISE."

CHAMBERING SLIDES TO PREVENT JAMMING

EVERYONE who has had experience with the old-fashioned vice will know that after the hand lever has been in use for a long time, the eye of the screw in which the lever works becomes bell-mouthed at each end, with the result that the effective length of the hole is so short that the lever jams and it becomes quite difficult to slide it through the eye.

In the modern vice a hole is frequently drilled crosswise through the hole in the eye so as to cut away about the middle third of its length. Then the length of bearing can never be less than the diameter of the cross hole, and the lever never jams.

It is an advantage to chamber, in this or some equivalent manner, the middle of every slideway used in instrument construction, when the slide is subject to any turning moment which tends to bell-mouth the ways.

THE TAYLOR-HOBSON RESEARCH LABORATORY, LEICESTER.

SHELLAC CREOSOTE CEMENT

Communicated by the BRITISH SCIENTIFIC INSTRUMENT RESEARCH ASSOCIATION

THE cement, of which the formula and method of preparation are given below, was the outcome of an investigation prosecuted in the laboratories of the British Scientific Instrument Research Association by Mr H. L. Smith, B.Sc., F.I.C., with a view to producing a material less brittle than shellac, more adhesive and free from the disadvantage of tending to become infusible by repeated heating.

The formula is as follows:

Shellac*	50 parts by weight
Wood creosote	5 " "
Terpineol	2 " "
Ammonia (sp. g. 0·880)	1 " "

Add the ammonia, terpineol and creosote to the shellac and gently heat until complete fusion has taken place, stirring well to ensure homogeneity.

The fused mass can be poured into moulds to form rods of suitable size. This product can readily be fused for use when required for making joints between metal, glass and many other materials which are not altered when gently heated. The surfaces should be perfectly clean and should be warmed before applying the cement.

* To ensure the maximum strength and fusibility, the shellac should be of good quality, *e.g.* a bright orange shellac.

CORRESPONDENCE

I WISH to bring to the notice of the manufacturers of physical apparatus in Great Britain that many firms do not keep this laboratory supplied with copies of their catalogues (particularly recent issues and prices) so that considerable difficulty is experienced in placing some of our orders in the British Isles. On the other hand, foreign manufacturers, particularly certain of those in the United States of America, are exceptionally good in this respect.

The tariff regulations of the Commonwealth of Australia have been worded so that British-made scientific apparatus, if none of equal quality is made locally, is admitted free of duty, and foreign-made apparatus is admitted free if there is no British-made article of equal quality. It is therefore important to us to possess details of all British-made scientific apparatus.

May I mention a small matter? This laboratory requires a large coloured chart of the Solar Spectrum showing the Fraunhöfer lines. If any of your readers are printers of such charts, will they please inform our agents, Messrs Jepson Bros., 42–46 Whitecross Street, London.

T. H. LABY,
Professor of Natural Philosophy.

NATURAL PHILOSOPHY DEPARTMENT,
THE UNIVERSITY OF MELBOURNE.

TESTING AND CALIBRATION OF METERS

I AM very much obliged for the article on "Electrical Test Room Equipment" which appeared in the October number of the *Journal*, and which is extremely helpful to us. I should also like to express through you my thanks to Dr Alexander Russell for his note on the same subject. With this information we can now go ahead quite satisfactorily.

I should like to take this opportunity of complimenting you on the *Journal*, which is especially useful and interesting to people like myself who are so far distant from England.

A. C. KELLY,
Chief Electrical Engineer.

FERROCARRIL DE BUENOS AIRES AL PACIFICO.

BALLISTIC PAPER TEARING TESTER (*Journ. Sci. Insts.* 1926, **4**, pp. 5–8)

THE main object of the proposed method would seem to be its application to rather small test specimens. Pickard showed some years ago in the *Journal of the Textile Institute*, 1919, **10**, p. 240, a similar arrangement for testing woven fabrics, but was unable to find any relation between his results and any known property disclosed by stress and strain tests in tension and in one plane.

More recently Denham has described (*Journ. Text. Inst.* 1924, **15**, p. T 291) a device for ballistic tests on small specimens, and I have to suggest that a modification of this instrument would be suitable for paper, with the advantage that the break would be in pure tension instead of being complicated by shearing as in the case of Booth's and Pickard's instruments. I may further suggest that an instrument be devised for ballistic tests of resistance to the tearing or "ripping" of either paper or fabrics, and that a slight modification of Denham's instrument, or of that devised by the Cotton Research Association, should not be difficult and should be attempted with this object in view.

I do not question the value of Booth's method as a means of producing empirical results of practical value, but it seems to me that the modification suggested should give it a better title to consideration as a scientific instrument without prejudice to its practical value.

There seems to be no doubt that ballistic tests of paper and fabric will largely replace pure tensile tests for commercial purposes, since they yield results which correlate stress and strain into a real and useful figure of what we call "strength." The simplicity of the machines employed, the rapidity of the test and the absence of driving mechanism, other than that of a falling weight, constitute advantages that are bound to be reflected in wider adoption of this method in works' practice.

J. H. LESTER.

COST OF ENGLISH INSTRUMENTS

YOU may be interested to see an extract from a letter from a correspondent (a member of the Institute of Physics) in Australia. It has to do with scientific instruments. Dealing with the question of obtaining an Aitken dust-counter for use in connexion with observations of atmospheric electricity, he writes:

"He borrowed an Aitken from the Bureau and got very encouraging results with it. The Department of Terrestrial Magnetism has included dust-counting in the routine work at its observatories. They were unable to get any English firm to manufacture the Aitken portable instrument for some time. Finally one firm offered to do the job at a ridiculous price. They had to ask an American firm to make them. The price the latter asked was about one-fourth of the English price. Such things seem to be happening quite frequently in England and it is a great pity."

NAPIER SHAW.

THERMAL CONDUCTIVITIES OF METAL RODS

REFERRING to Prof. G. W. Todd's paper in the January number of this *Journal* on "A method of comparing the thermal conductivities of metal rods," I would call his attention to a paper by Berget, *Comptes Rendus*, 1892, **114**, 1350, in which such a method is suggested. He proposed to use an interference method for the measurement of expansion, and, further, to make the necessary measurement of the coefficient of expansion with the same apparatus, by uniformly heating the bars.

E. D. VAN REST.

FOREST PRODUCTS RESEARCH LABORATORY,
IMPERIAL FOREST INSTITUTE,
UNIVERSITY OF OXFORD.

THE HEAPE AND GRYLLS MACHINE

IN Mr Connell's careful article on "The Heape and Grylls Machine for High Speed Photography," which appeared in your issue of December (No. 3, vol. IV), he devotes a paragraph to the "History" of the conception of the idea and the design and construction of the machine, with regard to which we desire to add a few lines.

With the history of the conception of the idea we would not trouble you, but so far as the design and construction of the machine are concerned we would say that we did not submit our original conception to the manufacturers; we took it to Professor C. V. Boys, who, prompted by friendship, lavished on our project all the adroitness and skill in mechanical device of which he is master. We were in conclave with Professor Boys many times, and in the end he designed the essential parts of the machine, and, further, took the

trouble to visit Messrs Thomas Cooke & Sons (now Cooke, Troughton & Simms, Ltd.) at their works in York, to explain to them his schemes, and to deposit with them his drawings.

It was these schemes which formed the basis on which Messrs Cooke & Sons most careful and accurate work was founded, and thus the success of the venture attained.

MANOR LODGE,
BISHOP'S DOWN,
TUNBRIDGE WELLS.

W. HEAPE.
H. B. GRYLLS.

REVIEWS

Polyphase Induction Motors. By R. D. ARCHIBALD, D.Sc., M.I.E.E., A.M.I.C.E. Pp. 88. Chapman & Hall. Price 5s. net.

As stated in the author's preface, this book assumes a knowledge of alternating currents. It proceeds immediately with the principles of the induction motor in its simplest form, comparing it with the alternator and transformer.

By various stated assumptions which are all sufficiently near the truth for practical purposes a simple circle diagram is drawn and power, loss, torque and slip are derived.

The magnetic circuit is treated in a short chapter which also discusses leakage, flux and the circle coefficient.

A typical 60 H.P. induction motor is examined in its chief design details, the next chapter dealing with operating characteristics. Starting, speed, torque, etc. are discussed and also the characteristics of the induction generator, M.M.F. and the transferring of rotor constants to the stator appear in the appendix, a few examples following.

This book should be of use to those who, having a fair knowledge of transformers, generators and A.C. circuits, wish to gain a working knowledge of the induction motor, without going too deeply into its theory.

J. B.

Surface Equilibria of Biological and Organic Colloids. By P. LECOMTE DU NOÜY. Pp. 212. Chemical Catalog Co., New York, 1926.

This book, which is one of the monograph series of the American Chemical Society, deals with the author's researches on some phenomena due to surface tension in biological and organic colloids. The tensiometer used is of the type in which a metal ring is pulled out of the liquid by means of the torsional stress in a wire. It has been carefully designed to afford great precision and rapidity of measurement.

With this improved technique the time required for the establishment of equilibrium conditions at an interface has been examined in the case of many colloidal solutions. The adsorption in the surface layer, though rapid at first, may require several hours for complete equilibrium; hence caution must be used in applying the thermodynamical equation of Gibbs. Other results obtained by the tensiometer allow a calculation to be made as to the thickness of a monomolecular layer, and in the case of sodium oleate, the dimensions of the molecule, and the value of Avogadro's constant.

The effect of colloids on the crystallization of sodium chloride has been studied. Whereas a solution of pure salt evaporating in a watch glass deposits large crystals in the centre, a trace of a colloid causes small crystals to form at the edge.

Curious results are obtained when both sodium oleate and blood serum are added to water. The surface tension drops to a low value in a few seconds, but rises again and reaches its initial value in 7 or 8 minutes. The explanation is that the small oleate molecules are adsorbed by the large serum molecules and thus these colloids neutralize each other. This method has been applied to detect concentrations of egg albumen as small as 10^{-8}.

The prevailing colour of the book is biological but the physical and chemical results and the novelty of the attack should arouse interest among all classes of scientists.

R. T. B.

Physico-Chemical Methods. By JOSEPH REILLY, M.A., D.Sc., WILLIAM NORMAN RAE, M.A., F.I.C., and THOMAS SHERLOCK WHEELER, Ph.D., B.Sc. London. Pp. 735. Methuen & Co. 30*s*. net.

This book deals with the experimental methods of physical chemistry very much on the same lines as in K. Arndt's *Physico-Chemical Technik*. It is divided into ten sections which, after an introduction, deal with the physical chemical laboratory and its equipment, general operations, physical measurements, some properties of solution, some properties of gases and vapours, thermochemistry, optical measurements, electrical properties, and miscellaneous. Especially noteworthy are the chapters on pumps, mass, the measurement of pressure, the determination of the conductivity of electrolytes and X-ray analysis.

In the chapter on radiation methods of measuring temperature the "disappearing filament" type of pyrometer, which has come into extensive use in recent years, might have been mentioned, and in the chapter on the measurement of surface tension a discussion of the "drop weight" method which is based entirely on the experiments of Morgan is given but no reference is made to the important subsequent work of Harkins and his collaborators and of Iredale. In the chapter on viscosity after pointing out the importance of this property in the study of colloid systems it might have been advisable to describe one of the most important instruments for this purpose, the Couette or Hatschek-Couette type which involves a constant rate of shear. In the description of many forms of pump available the authors do not perhaps tell the reader quite enough about the advantages and disadvantages of the forms described, *e.g.* in discussing the Toepler pump we are told that "it has the disadvantage of requiring personal attention" but the great advantage this pump possesses in the ease with which the gas being pumped off can be collected (should this be necessary) is not mentioned. Also a Toepler pump was described some years ago by Maass which does not require personal attention.

In writing a book of this type it must have been a matter of considerable difficulty to the authors to find room for all the material which they wished to include; moreover, as it is primarily for the advanced student and technical and research worker we cannot help thinking that the portions dealing with the vernier, the micrometer screw gauge and the spherometer, which after all are to be found in any elementary textbook of practical physics, might with advantage be omitted. This also applies to the portion of chapter XIII dealing with the examination of butter fat. Surely a textbook on food analysis is the proper place for this. In spite of these minor defects this is an excellent book and we can heartily recommend it to all persons engaged in physico-chemical work. It is well printed in excellent type but the diagram on page 342 appears to be upside down.

L. L. B.

THE CAMBRIDGE INSTRUMENT COMPANY have drawn our attention to the fact that the illustration of the Campbell Capacitance Bridge which appeared in their advertisement on p. xii of the February number was printed upside down. The mistake is greatly regretted.

TABULAR INFORMATION ON SCIENTIFIC INSTRUMENTS

XIX. HOT-WIRE AND THERMO-JUNCTION VOLTMETERS AND AMMETERS

THE table overleaf gives particulars of various types of hot-wire and thermo-junction instruments, as furnished by their respective manufacturers. A separate copy of this table may be obtained by any subscriber on application to the Secretary of the Institute of Physics, 1 Lowther Gardens, South Kensington, S.W. 7.

XIX. HOT-WIRE AND THERMO-JUNCTION VOLTMETERS AND AMMETERS

Type and number	Principle (expansion or thermo-junction)	Range (amps or volts)	Length of pointer (mm.)	Length of scale (mm.)	Accuracy % of top reading	Dimensions of case	Remarks or special features	LIST PRICE £ s. d.
Maker:—EVERETT, EDGCUMBE & Co., Ltd., Colindale Works, Hendon, N.W. 9.								
Z	Thermo-junction	Any range from 20–100 mil. amps up to 4–20 amps	33, 38 or 73	58, 67 or 150	B.S.S. 1st grade	2½, 3½ or 6″ dial. Switch-board or portable	Power or radio frequencies. Also supplied as low range voltmeters	Varies according to range, etc.
T	Thermo-expansion (hot wire)	Any range from 50–250 mil. amps up to 20–100 amps	33, 38, 73 or 98	58, 67, 150 or 200	B.S.S. 2nd grade	Ditto	For D.C. or A.C. at power frequencies; or up to 5 amps for radio-frequencies. Also supplied as low range voltmeters	
Z or T with current transformer	Thermo-junction or thermo-expansion	Any range from 2–10 up to 200–1000 amps	Ditto	Ditto	Type Z 1st grade, type T 2nd grade	Ditto	For radio frequencies only	
Maker:—JOHNSON & PHILLIPS, Ltd., Charlton, S.E. 7.								
H.W.	Expansion	0–1 up to 0–5000 volts 0–0·2 up to 0–5000 amps	85	120	1 voltmeter 2 ammeter	225 mm.	Switchboard pattern, front or back connected	4 10 0 to 21 0 0 4 10 0 to 26 0 0
Maker:—THE STONEBRIDGE ELECTRICAL Co., Ltd., Victoria Road, N. Acton.								
HTv	Expansion	5–300 volts	85	150	B.E.S.A. 2nd grade	220 × 200 × 180 mm.	Magnetic damping. Self-contained for single 2 and 3 ranges. External series resistances can be supplied for pressures up to 1500 volts Switchboard or Portable Pattern	6 14 0 to 8 15 0 2 15 0 to 10 10 0
HTa	Expansion	1–200 amps	85	150	B.E.S.A. 2nd grade	220 × 200 × 180 mm.	Magnetic damping. Single range self-contained up to 200 amps. Double range up to 100 amps External shunts supplied up to 2000 amps Switchboard or Portable Pattern	7 0 0 to 9 10 0 4 0 0 to 13 0 0
Maker:—WESTON ELECTRICAL Co., Ltd., 15 Great Saffron Hill, London, E.C. 1.								
412 ammeter	Thermo-couple	·002–1000 amps	90	133·5	½	8½ × 7½ × 4½	Made as single range ams and mil. ams for use upon D.C. or radio frequencies with the same degree of accuracy	67 0 0
412 voltmeter	Ditto	0·3–150 volts	90	133·5	½	8½ × 7½ × 4½	Ranges below 1 volt have a sensitivity of approx. 27 ohms per volt. Above 1 volt a sensitivity of 125 ohms per volt and 3-volt instruments and above can be made with a sensitivity of 500 ohms per volt. For either D.C. or A.C. to 3000 cycles per second	67 0 0
492 voltmeter	Ditto	1–50 volts	88	135	Better than ½ % at 600,000 cycles, and better than 1½ % at 1,500,000 cycles	8 × 7½ × 4½	Ranges 3–20 volts have a sensitivity of 500 ohms per volt	94 0 0
400	Ditto	1–750 amps	86·2	165	1	7½″ dia. 4″ deep	Switchboard instruments for audio or radio frequencies and may be checked upon D.C. They have a safe overload of 50 %	17 0 0
401	Ditto	1–30 amps self-contained	55	68·6	1	4½″ dia. 2″ deep	Round pattern switchboard instruments having a safe overload capacity of 50 %. May also be checked on D.C.	12 0 0 12 0 0
425	Ditto	125 mil. amps–20 amps	34·3	59·7	2½	2½″ dia.	Ammeters have a safe overload capacity of 50 %. Mil. ammeters and galvanometer much larger overload capacity	4 5 0

JOURNAL OF SCIENTIFIC INSTRUMENTS

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PROGRESS IN THE DESIGN AND CONSTRUCTION OF ELECTRICAL INSTRUMENTS. By DR C. V. DRYSDALE.

(*Continued from p.* 217)

II. LABORATORY INSTRUMENTS

The number and variety of electrical laboratory instruments has now become so enormous that it is obviously impossible to refer to them in detail, and my remarks must be confined to the most salient features of progress and modern tendencies.

Long Period Galvanometers

Even thirty years ago moving magnet and moving coil galvanometers had reached nearly their present form, and although the former type has been materially improved in sensitivity by Broca and by Paschen, especially by the introduction of quartz fibre suspensions due to Prof. Bays in 1889, the moving needle galvanometer has fallen so much into disuse owing to the superior freedom from magnetic disturbances of the moving coil form, that these improvements only appealed to a few research workers who required the maximum possible sensitiveness. During the last two years, however, Prof. A. V. Hill and Mr A. C. Downing at University College, with the assistance of Dr Daynes of the Cambridge Instrument Co., have effected improvements in the moving needle galvanometer which may almost be described as epoch marking, and which may possibly result in its ascendency over the moving coil instrument. By careful design of the moving system and making it of extremely small dimensions with cobalt steel magnets, these workers have succeeded in obtaining a figure of merit of about 50,000 or a deflection of 50,000 mm. per microampere at a metre for a 1 ohm galvanometer and a 10 sec. period; a sensitivity far surpassing anything before obtained, and about 500 times that of the Kelvin four-coil galvanometers. Wonderful as this achievement is, it would not itself make the moving needle a popular instrument, as it was already superior in sensitivity. But Prof. Hill and Mr Downing did not stop there and applied themselves towards overcoming the real objection to the moving needle galvanometer—its susceptibility to magnetic disturbance—by magnetic screening. Many attempts have been made in this direction by enclosing the galvanometer in massive soft iron bells, but only with very moderate success and with almost prohibitive masses. Early last year, Mr Dye contributed a paper on the "Theory of Screening" to the *Journal of Scientific Instruments* which led me to suggest that a high degree of screening might be obtained by quite a thin cylinder of the new high permeability nickel iron alloys known as Permalloy or Mumetal, which could be substituted for the ordinary brass case of the instrument. This suggestion was immediately adopted by Prof. Hill and Mr Downing, with a result fully realising my expectations, and this has apparently overcome all difficulty with magnetic disturbances, as the instrument can be used within a short distance of a motor with hardly any disturbance when it is started or stopped*. As this screening is so easily

* *Journ. Scient. Instr.* (July, 1926).

obtained, the superior sensitivity of the moving needle galvanometer should give it a considerable lead; and it has the two additional advantages of enabling coils of very low resistance to be employed for high P.D. sensitivity and of not being overdamped on low resistance circuits.

A very simple experiment clearly shows the effectiveness of this screening. If we suspend a light Cobalt steel magnet from a quartz fibre it oscillates when disturbed with a quick period of say about 1 sec. owing to the control of the earth's magnetic field, and it is of course strongly deflected by a bar magnet at some distance. On enclosing this system in a Mumetal cylinder closed by plates of the same material the rapid oscillation is replaced by one of 10 secs. period or more, which is mainly due to the control of the fibre; and the external bar magnet has hardly any effect.

As regards moving coil galvanometers for ordinary testing purposes there has been little change since the introduction of the narrow coil and strip suspension by Ayrton and Mather about 1893, and this type is likely to be the permanent one. By the adoption of Cobalt steel magnets, a greater sensitivity may perhaps be obtained, but the great difficulty with such galvanometers is to make and keep the coil entirely free from magnetic material, and this seriously militates against the use of stronger fields. Although great advances have been made in producing wire and insulation free from magnetic material, there is always a risk of minute particles of iron dust in the air sticking to the coil. Another objection to a strong magnetic field is that it increases the critical resistance of the galvanometer so that the gain in sensitivity is in some cases illusory.

Short Period Galvanometers and Oscillographs

In the early days of galvanometer construction emphasis was almost entirely laid on sensitiveness, which was obtained by reducing the control as far as possible, so that periods of 20 secs. or more were common. As time went on, however, the need for more rapid observations or of following varying phenomena became felt, and the first advance, as already mentioned, was made by Professors Ayrton and Mather when they took steps to reduce the moment of inertia of the moving coil galvanometer by making the coil of the narrow elongated form to which we have become accustomed. This brought the figure of merit of the moving coil galvanometer to about 100, which has been further increased to about 400 by using long suspensions and small mirrors. Within the last few years Dr Moll of Utrecht has again greatly improved the sensitivity by using a small coil in the field of an electromagnet, and has secured a sensitivity of 200 mm. per microampere with a 50 ohm galvanometer and a period of about 1·3 secs., implying a figure of merit of about 2500.

The first great need for rapid indication, however, was for the direct recording of alternating current wave forms. In 1893 Blondel conceived both a moving iron and a bifilar type of oscillograph, and Duddell in 1897 produced a high-frequency bifilar oscillograph having a periodic time of only 1/10,000th sec. which has persisted with small modifications to the present day. The great importance of such instruments has led to their continued development, and in 1921 a portable form of 3-element oscillograph using an overrun glow lamp was introduced in America. The Cambridge Instrument Co. have recently introduced a similar portable instrument, which seems likely to fill a widely felt want.

For somewhat less rapid variations, however, the single fibre or 'string' galvanometer introduced by Einthoven in 1901 has proved a most valuable addition to our testing equipment, as it is much more sensitive than the oscillograph, and during the war it did valuable service in sound-ranging and the recording of small time intervals. A fine silvered quartz or glass fibre is usually employed in the gap of a powerful electromagnet, and the periodic time and sensitivity can be varied by the tension on the fibre. As the movement

of the fibre is transverse to the field it has to be viewed through the poles by a microscope, and the whole instrument is somewhat costly but its figure of merit is very high, about 40 mm. per μA at ·01 sec. or 5 mm. at ·0035 sec. periodic time, giving a figure of merit of no less than 1,500,000.

On practically the same principle as the Einthoven galvanometer, but with permanent magnets instead of the bored electromagnet, is the loop galvanometer of Messrs Carl Zeiss, Fig. 4. In this instrument the current passes through a U-shaped loop of thin strip, but a kink is made at the bottom of the loop so as to give a short vertical portion which crosses the field of a microscope with a scale in the eyepiece. The loop is enclosed between two plates of glass like a small lantern slide, and two horseshoe magnets are arranged so as to give two opposite fields across the long vertical sides of the loop which consequently moves in its own plane when current is passed through it. When the loop hangs vertically downward its rigidity is assisted by gravity, but the whole case containing the loop and magnets

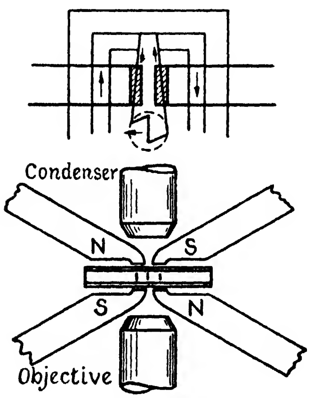

Fig. 4. Zeiss Loop Galvanometer

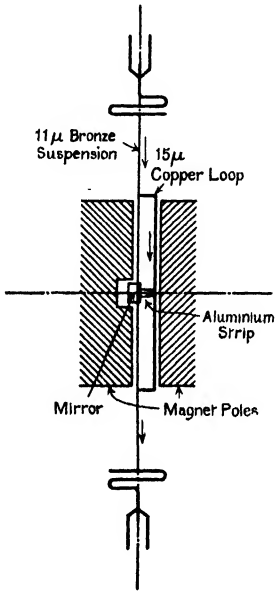

Fig. 5. Torsion String Galvanometer

is mounted in horizontal trunnions so that it can be turned upside down, in which case gravity opposes rigidity and the resultant control is very small. The flat strip between the two glass plates gives very effective air damping so that the instrument is generally more than critically damped, and it takes up its full deflection in about 0·5 sec., the sensitivity being about 18 eyepiece divisions per microampere for a resistance of 6 ohms, with loop hanging.

Although the string type of instrument is very sensitive and has the advantage of being self-contained, the optical arrangements make it very costly, and in order to get sufficient light for photographic recording a good deal of sacrifice of magnification has generally to be made.

Within the last few months, however, a very simple form of quick acting galvanometer has been devised by Meinheer van Dyck of Utrecht, which he calls a Torsion String Galvanometer (Fig. 5). It has a single fibre as in the Einthoven instrument, consisting of an 11μ silicon-bronze wire between spring supports, but a 15μ copper wire lies parallel to this string and is bent over and soldered to it at the top and bottom of the gap so as to shunt the suspension over its middle half and divert the bulk of the current into it on account of its lower resistance. It thus forms what may be termed a half coil which tends to rotate

round the suspension, and as the arrangement is unsymmetrical the small mirror is mounted on the other side of the suspension so as to balance the loop, and moves in a slot in the pole face. The sensitivity for a 10 ohm instrument of this type is given as 3 mm. per μA at a metre with a periodic time of 0·01 sec. and it can be used with the ordinary lamp and scale. Its figure of merit appears to be practically the same as that of the Einthoven Galvanometer.

The chief defect of practically all existing oscillographs is, however, their lack of sensitivity, owing to the great control which is necessary to secure the small periodic time required (the Duddell 10,000~ oscillograph requires about 0·1 amp.), and this renders them unsuitable for telephonic measurements in which currents of only a few milliamperes at most are employed. Various attempts at increasing the sensitivity have been made, notably in the recent Dubois form of oscillograph in which the movements of a polarised iron tongue are communicated to a mirror through a ligament, but these have been at the expense of reducing the frequency to about 2000 per sec., and as telephonic measurements are generally made at 700~ or higher this is a serious drawback. It may therefore be pointed out that there appears to be room for a radical departure in the principle of recording devices which should enable correct wave forms of high frequencies to be obtained without any attempt at making a high-frequency system.

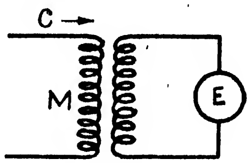

Fig. 6

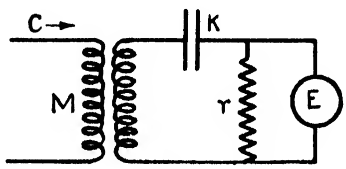

Fig. 7

The equation of motion of a body having mass m, damping constant b and control k is $m\ddot{x} + b\dot{x} + kx = F$, where F is the applied force. In existing oscillographs k is made so large that the third term only is of importance, so that $kx = F$ or $x = \frac{F}{K}$. The displacement is therefore proportional to F, or to the current C, if $F \propto C$. Suppose, however, that k and m are both small so that $b\dot{x}$ is the important term, then

$$b\dot{x} = F \text{ and } x = \frac{1}{b}\int F dt + A.$$

Let us suppose that the moving system is an electrostatic [illegible] $X = aV$ and that it is fed from the secondary of a mutual inductance M as in Fig. 6. Then $V = M\frac{\partial C}{\partial t}$, $F = aM\frac{\partial C}{\partial t}$ and $b\dot{x} - aMC$ from which $x = \frac{a}{b}C + A$, so that the variations of the displacement x follow those of C exactly, although there may be a drift of zero which can be practically eliminated by a small control. A single fibre electrometer working in oil or even in a confined air space, or a heavily damped Einthoven string galvanometer in series with a condenser will realise this condition.

We may carry this principle even further by removing the damping, say by enclosing the fibre in a vacuum, so that both b and k are negligible. In this case only the first term is of importance, or $m\ddot{x} = F$, and if we can make $F = c\ddot{C}$ then $x = c/m\,(C + At + B)$. If we connect this fibre as in Fig. 7 across a resistance r in series with a capacity K which is connected in series with the secondary of the mutual inductance M it is easy to see that if K is so small that the current in the secondary of the mutual inductance does not affect its P.D. the P.D. across the latter $= KrM\ddot{C}$ and the required condition is fulfilled. An

ordinary moving magnet galvanometer, say of the Paschen type, may be substituted for the shunted electrometer in this case. With a small amount of damping and control At and B will be negligible over a short period and a true record will be obtained with a simple slow undamped system.

Mr S. Butterworth has recently independently conceived the above principle and has already carried it into practical effect with useful results. It appears quite possible that it will lead to a material advance in oscillograph technique.

Up to the present however the greatest advances in the recording of high frequency phenomena have been made by the Cathode-ray oscillographs which will be described later.

Vibration Galvanometers

As soon as null or balancing methods began to be employed in A.C. testing the need for a sensitive detecting device became apparent, and although the telephone receiver was fairly satisfactory for sonic frequencies, it was almost useless for measurements at ordinary supply frequencies. It is believed that the late Dr Silvanus Thompson had the idea of a tuned vibration galvanometer some years before any practical demand arose for it, but probably the first working form of instrument was that of Rubens about 1905 in which a magnetised needle was fixed on a taut suspension strip the working length of which could be varied by sliding clips in order to tune it to any required frequency, and was set in vibration by passing the current round a coil. This instrument was moderately sensitive but was very difficult to tune, and a great advance was made by Mr A. Campbell in 1907 by using a small light moving coil with bifilar suspension in a permanent magnet field, and tuning by varying the tension on the suspension. In 1909 Mr Duddell carried this principle still further by eliminating the coil and using a long double strip as in his oscillographs and produced a very sensitive instrument covering a frequency range of from 50 to 2000 p.p.s. Meanwhile the present writer had devised, about 1910, a vibration galvanometer of a very simple form with a small moving magnet as in the Rubens instrument but mounted on a silk fibre so as to have very little control, and employing a permanent magnet with sliding poles and variable magnetic shunt for tuning. As originally made, this instrument was moderately sensitive, but was not very quick in response owing to the inertia of the large mirror employed, but great improvement has since been effected by making the mirror smaller and of stainless steel, and also by substituting an electromagnet for the permanent magnet, thus allowing the frequency to be varied over a wide range by controlling the exciting current without touching the instrument, which is often a great convenience.

In spite of the high sensitivity which has been attained with the moving coil type of vibration galvanometer, the writer is inclined still to favour the moving iron type for several reasons. It is certainly the most simple and robust in construction, the coils can easily be changed for low or high resistance working, its inertia is all useful since the mirror is itself the active mass; and the possibility of tuning at the testing table without disturbing the instrument is a great advantage. In addition, however, there is another important point of principle which needs to be borne in mind. In the double strip instrument of the Duddell type the galvanometer is sensitive not only to the fundamental frequency, but to various harmonics, which is liable to cause confusion in testing with irregular wave forms, and even the moving coil instruments sometimes give trouble by flexure of the coil; and the only way of avoiding this is to concentrate the mass into a single rigid element and for the control to act directly on it. Lastly, there is an advantage in many cases in making the winding differential, as if there is any great difference of potential between the circuits and earth, capacity currents are likely to cause disturbances which can be largely reduced,

if not entirely eliminated, by interposing one of the windings in each lead. This can be more easily effected with fixed coils, although the writer has obtained the same effect with the Duddell galvanometer by separating the two strips and attaching them to a silk fibre passing over the pulley.

Pointer galvanometers. However valuable and necessary reflecting galvanometers may be, there is very great need for sensitive instruments which are portable, and in this respect the string galvanometers have a great superiority over torsional instruments as no balancing is required and the mass of the fibre is so small as to eliminate all effects of gravity when the instrument is tilted. Where moderate sensitivity only is required, pointer galvanometers are frequently sufficient, and the single-pivot moving coil galvanometer of Mr Paul has proved of great value in cases such as on board ship where no other instrument could be used. A 50 ohm instrument of this type will deflect over its whole scale for $120 \mu A$ and a 1000ω semi-suspended instrument with $6 \mu A$.

The following table, based principally on information given by the Cambridge Instrument Co. summarises the performance of the various types of galvanometers at the present time:

Moving Magnet Galvanometers

	Resistance ω	Periodic time sec.	Deflection mm. at 1 metre per μA	per μV	per μ coulomb	Figure of merit
Broca	10–1000	6–10·5	355–2770	2·8–35·5	210–1700	150
Paschen	·75–4000	6	1000–30,000	7·5–1330	—	3000–4000
Paschen improved	—	—	—	—	—	up to 50,000

Moving Coil Reflecting Galvanometers

Ayrton Mather	25–400	3·5–6	110–800	1·4–6	116–1440	80–400
Moll	47	1·3	200	42	970	2500

Moving Coil Pointer Galvanometer

Suspended coil	65	11	15–20 microamps for full scale
Unipivot	10, 50, 1000	4 to rest	240, 120, 24 microamps for full scale
Unipivot semi-suspended	10, 1000	12 to rest	30, 6 microamps for full scale
Double pivot	30	3·7 to rest	100 microamps for full scale

String Galvanometers

		Resistance ω	Periodic time, sec.	Magnification		Figure of merit
Einthoven	3μ plated glass fibre	4000	·01, ·0035	600	40·5	1,500,000
	12μ copper	13	·0085	600	2	1,000,000
Small string	11μ copper	11	·00125	40	·001	25,000
Torsion string	11μ silicon bronze	10	·01	—	3	1,200,000
Zeiss loop	—	6	overdamped	—	140	—

Vibration Galvanometers

	Frequency ~	Effective resistance ω	Deflection mm. per μ amp.
Campbell	50, 100, 350, 750, 1000	500, 350, 160, 52, 35	60, 50, 3, 0·5, 0·2
Moving iron (6 mm. diam. mirror)	50	1000, 250, 120, 40 10, 1 (d.c.)	20, 10, 6, 4, 2, 0·5
Tinsley moving coil	5–1500	80–3·5 (d.c.)	1270–8·5

Electrometers

Very great advances have been made during the past few years in sensitive electrostatic instruments owing to the stimulus of research in radio activity, and we now have instruments which greatly surpass the early electrometers of Lord Kelvin, good though

these undoubtedly were. The great need in the case of radio activity research was for sensitivity combined with low electrostatic capacity, and consequently the first improvements were made on gold leaf electroscopes. In 1903 Prof. C. T. R. Wilson devised the tilted single gold leaf electrometer with a single hanging gold leaf near to an inclined plate with sliding adjustment, and by varying the tilt of the instrument and distance of the plate, the deflection could be made extremely large and even unstable over part of its range. This deflection was observed by a microscope with eyepiece scale and with 200 volts on the plate 2 divisions deflection could be obtained for ·01 volt on the leaf and with an electrostatic capacity of only a few centimetres. This form has recently been improved by Dr G. W. Kaye (Fig. 8), and the figures above are for this improved type.

Material improvements have also been made in the quadrant electrometer by reducing its dimensions and therefore its moment of inertia, and by using gilded quartz fibres for the suspension. The first great step in this direction was made by Dolezalek, and the most recent form of this electrometer with a 4μ gilded quartz suspension gives 150 mm. deflection

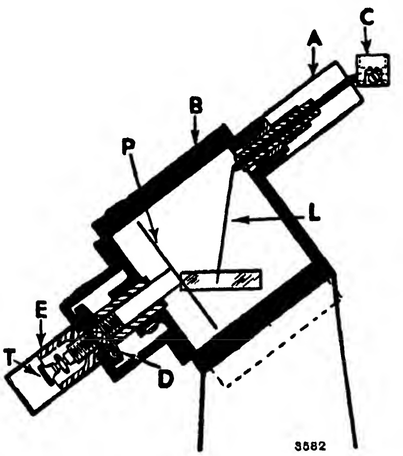

Fig. 8. Wilson and Kaye Tilted Gold Leaf Electrometer

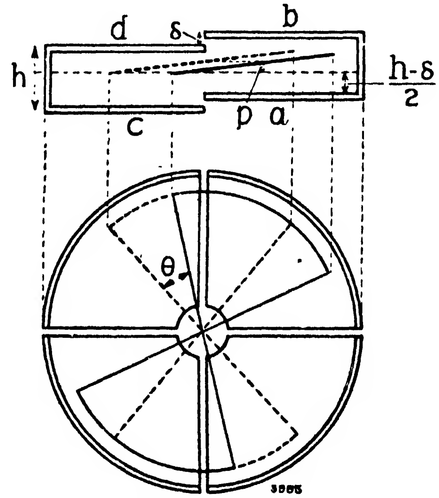

Fig. 9. Compton Electrometer

at a metre with 100 volts on the needle and 0·1 volt between quadrants. One of the chief difficulties in the way of obtaining high sensitivity with the quadrant electrometer is the electrostatic control introduced by the P.D. between the needle and quadrant, and a very great advance has been recently made by Prof. Compton, Fig. 9, who has found that by slightly inclining the plane of the needle and arranging one of the quadrants to be raised or lowered this control can be varied and made either zero or negative*. With a 2 to 3μ gilded quartz suspension this type of electrometer will give from 15 to 140 mm. deflection at a metre for ·01 volt between quadrants with 50 volts on the needle, according as the electrostatic control is positive zero or negative; the time for steady reading varying however from 9 to 90 secs.

With normal control and idiostatic connection 3 volts alternating gives 450 mm. deflection at a metre. The capacity of the system is about 10 cm.

Following the Einthoven string galvanometer, string electrometers have been produced which are very sensitive and quick in reading and have an electrostatic capacity of only about 2 cm. so that they show an appreciable deflection on the impact of a single alpha particle. The fibre is mounted centrally between two narrow plates forming the "quadrants"

* See *Journ. Scient. Instr.* 3, No. 11 (Aug. 1926), 381.

which can be adjusted to give symmetry of deflection for equal positive and negative potentials, and the whole arrangement is simple and compact and can be mounted on an ordinary microscope. With a 2 to 3μ gilded quartz fibre and 25 volts between plates ·1 volt on the fibre gives a deflection of ·044 mm. or 5·5 scale divisions in a suitable microscope and with a critically damped motion of period less than 1 sec.

Lastly Prof. Lindemann has produced a torsion fibre electrometer, Fig. 10, which is the electrostatic analogue of the Dyck torsion string galvanometer having a 4 to 6μ gilded quartz fibre under tension and a needle of two gilded glass fibres 2 cm. long and ·02 mm. diameter mounted transversely and symmetrically on it. Four rectangular plates 1·5 cm. broad and 1 cm. high serve as quadrants and are slotted so as to allow the needle to pass through, and the whole system is mounted in a small sealed metal box with glass windows at the top and bottom, which can be placed on the stage of an ordinary microscope. ·35 volts across the quadrants gives ·4 mm. deflection or 136 divisions in the microscope for 1 volt on the needle.

In both types of string electrometer care has to be taken to make the supports of the suspension of the same coefficient of expansion as the fibre in order to avoid change of tension with temperature. Either quartz or nickel steel is suitable.

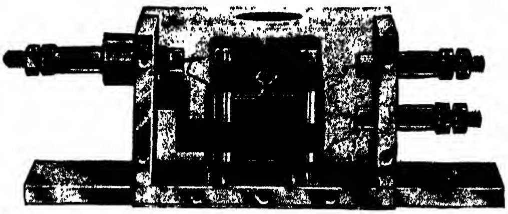

Fig. 10. Lindemann Electrometer

In addition to these laboratory instruments mention should be made of the sensitive electrostatic instruments devised by Addenbrooke and by Patterson and Rayner as voltmeters, wattmeters, and even ammeters for A.C. testing. Although these instruments have not the portability of electromagnetic instruments, they have the advantage of freedom from all inductance and eddy current errors, and of being easily adapted for all ranges by the help of suitable non-inductive resistances; and when carefully permanently installed give very accurate results.

Resistance Boxes, Bridges, and Potentiometers

As mentioned at the outset, considerable improvements have been made in resistance boxes and similar instruments since the old days of embedding in paraffin wax; and modern boxes now almost universally have their coils wound on large open metal tubes giving much better radiating surface. The growth of industrial research and the great extension of high-frequency work, however, call for further improvements and it is submitted that the time has come for a drastic revision of the whole design of resistance apparatus and bringing it more into line with engineering practice.

The makers of electrical machinery have long since found that insulating materials are unsuitable for mechanical support and that they should only be employed in thin layers or pillars tightly clamped between metal plates or reinforced by metal as far as possible; and it may be suggested that dynamo practice might well be adopted in resistance boxes. The dial of a switch type resistance box is similar to a dynamo commutator, and everyone knows the solid engineering construction of the latter, which is hardly affected even by burning out of the coils, and permits of truing up at any time; while the burning out of a

coil in a resistance box may easily soften and distort the ebonite slab so that the whole dial is thrown out of truth. An equally strong point against the ebonite slab is the deterioration of its appearance and insulation by surface oxidation due to light, and cases have been known where costly slide condensers have been rendered useless by their insulation falling to only a megohm or two. Again, modern high-frequency work has emphasised the importance of screening, which is making its appearance in radio apparatus, so that a completely enclosed metal case seems to be the right thing, especially as it can be filled with oil, and thus increase the current carrying capacity of the coils and the ease of determining their temperature.

We are therefore led to the conclusion that the most rational construction for sliding contact resistance boxes is to make each set of resistances and dial as a unit practically like an armature and commutator, and to enclose the whole set in an oil-filled metal tank. The idea of making the resistance dials in rotatable units first occurred to Mr A. C. Jolley in 1912, and boxes made up in this form have been put on the market by the Cambridge Instrument Co.; but they do not seem to have attracted much attention, in spite of their

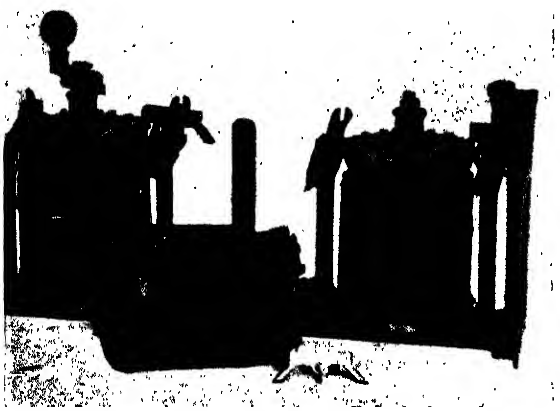

Fig. 11. Mr A. C. Jolley's Resistance Box

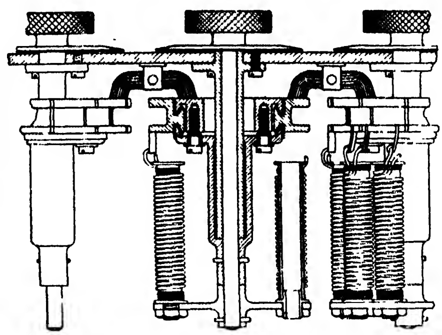

Fig. 12. Suggested Commutator Resistance Dials

manifest advantages. Fig. 11 shows the construction of this form of box, and Fig. 12 a sketch design on the lines above indicated, in which the dial is made up exactly like a dynamo commutator with mica insulation. The resistance units can be easily removed, so that a damaged coil can be repaired and the commutator turned up with the greatest ease; the brushes are of the simplest possible form and can easily be cleaned or replaced; and the copper tank gives large cooling surface and efficient high-frequency screening. The whole of the insulation is well protected from light, and mechanically supported. It is suggested that instrument makers would do well to consider the substitution of designs of this type for their present ones, and thus bring their resistance boxes, bridges and potentiometers into line with the more modern types of indicating instruments. Figs. 13, 14, 15 and 16 show, diagrammatically, suggested unit-dials for resistance boxes, potentiometer or Kelvin bridges, vernier potentiometers, and ratio coils, and Fig. 17 a 4 or 6 dial bridge made up from such units.

Although the construction of such commutators may appear at first sight more costly than of the usual screwed sectors, it must be remembered that they lend themselves very well to mass-production in a few standard sizes, and that a very great saving would result from the elimination of costly slabs of ebonite and of jigs for drilling off the various types of instruments. The keeping of a stock of dials of various resistances would enable any form of resistance box, single or double bridge, or potentiometer to be made up at a few

days' notice and thus avoid long delays, or the carrying of a large and costly stock of finished instruments.

Contacts. Although well-made plug contacts are certainly superior, the much greater convenience of switch contacts has brought them into increasing favour, and this is likely to remain the case. From measurements recently made by Mr A. C. Jolley it appears that a well-made plug of about 0·2″ mean diameter with a 9 per cent. taper may have a contact

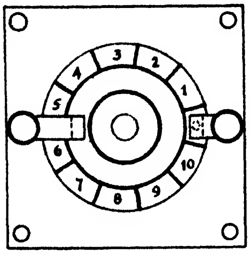

Fig. 13. Resistance Dial Unit

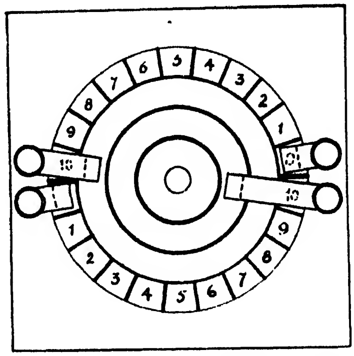

Fig. 14. Double Dial Unit for Potentiometer or Kelvin Double Bridge

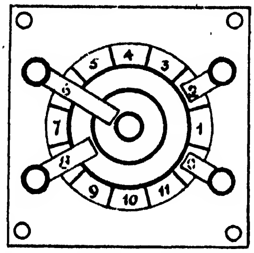

Fig. 15. Vernier Dial Unit

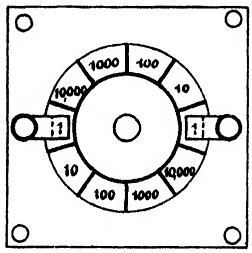

Fig. 16. Ratio Dial Unit

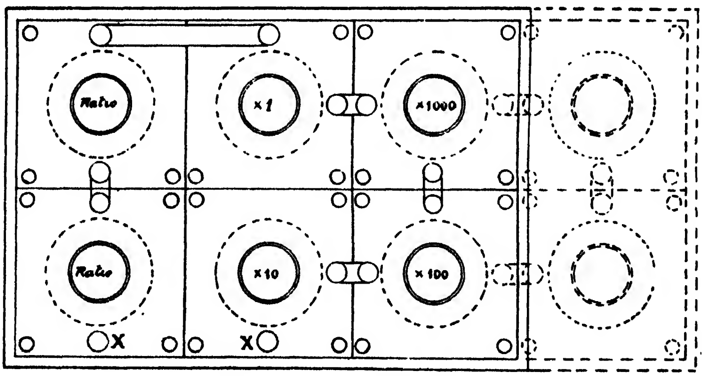

Fig. 17. Built up 4 or 6 Dial Bridge in Tank

resistance of only about 50 microhms; while the best form of highly laminated brush contact having an area of about 1 sq. cm. has a resistance of about 160 microhms, and 500 to 1000 microhms per contact is quite usual. High lamination and careful support and facing are essential for good brush contacts.

Non-inductive Resistance Coils. The ever-increasing stringency of high-frequency measurements has called for continued reduction in the time constants of the coils, and measurements made by the Washington Bureau of Standards showed that the ordinary double wound

coils on brass bobbins were somewhat inductive for coils of 10ω or less, almost exactly non-inductive for 100ω coils, and more anti-inductive for higher resistances in which the capacity between the turns more than compensated for the inductance. Various manufacturers have given attention to this matter and have succeeded by using glass or porcelain bobbins and by other methods in reducing the capacity effect in the high resistance coils. Messrs H. Tinsley and Co. have given me the following figures for the effective inductance of ordinary non-inductive resistances on brass tubes.

Resistance	1ω	10ω	100ω	1000ω
Effective Inductance	$+0\cdot3$	$+1$	-1	-5 microhenrys

The same firm has however recently introduced a very neat form of compensated coil which enables the higher resistances to be made exactly non-inductive. The coil is wound on two glass or porcelain conical bobbins, one of which is inside the other and can be moved axially so as to alter the distance, and hence the capacity between the two halves of the winding until the inductance is exactly neutralised. Although such a compensation is theoretically only exact for the frequency at which it is adjusted, the departure is probably

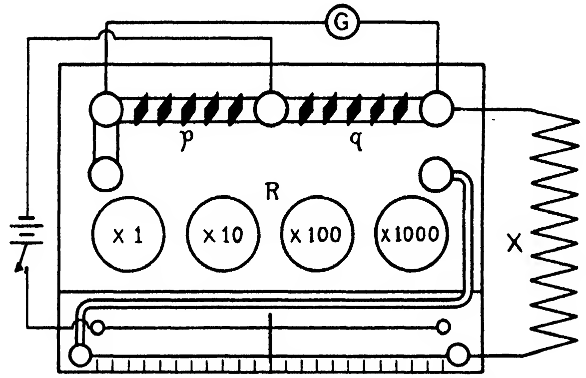

Fig. 18. Four-dial Bridge with Slide Wire

negligible over the whole range if it is effected at a high frequency. Devices for eliminating the effect of mutual capacity between the coils as they are added together have also just been introduced.

A most useful adjunct to the ordinary bridge which does not appear to be well known and the origin of which I have been unable to trace, is a simple bridge wire connected in series with the unknown resistance to the X terminals of the bridge as in Fig. 18, the battery lead being disconnected and joined to the slide wire contact. The arrangement is therefore equivalent to adding the resistances of the two portions of the slide wire to the X and R arms of the bridge respectively, and if equal ratio resistances are employed and the slide wire contact is set to the central position, this is equivalent to adding half the slide wire resistance to each arm, and balance is unaffected. If however the total resistance of the slide wire is $0\cdot1$ ohm and the contact is shifted to one end, this is equivalent to diminishing X and increasing R each by $\cdot05$ ohm or to increasing R alone by $0\cdot1$ ohm, and if the slide wire is divided into 200 divisions, each division is equivalent to $0\cdot001$ ohm. This simple attachment therefore enables resistances to be measured up to highest value of R to within $\cdot001\omega$ or less with great rapidity and without using unequal ratios, and is easily checked by altering R by $0\cdot1\omega$ and finding the new balance. It can be easily added to any existing bridge, and Messrs Tinsleys incorporate it in some of their types.

(*To be continued.*)

A SENSITIVE LONG-WAVE RADIO DIRECTION-FINDER.

By R. L. SMITH-ROSE, D.Sc., Ph.D., A.M.I.E.E. of the National Physical Laboratory.

[*MS. received 20th December*, 1926.]

SUMMARY. A description is given of a single-frame coil type of direction-finder which was constructed for the purpose of taking wireless bearings on long-wave transmitting stations at distances of several thousand miles. The precautions taken to overcome sources of error in these direction-finders are described in some detail, and a brief account is given of some typical results obtainable with the instrument.

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1. General

The radio direction-finder is now well-known as an instrument, which can be used to determine the direction of arrival of wireless waves, and which has an application to both the science and practice of wireless communication. The several commercial types of direction-finder now in use utilise the same fundamental principle of the reception of vertically polarised * wireless waves by a frame coil. In Fig. 1 *a* for example, let *C* represent a plane vertical loop rotating about a vertical axis in the field of an arriving wave whose component electric and magnetic forces are as shown. From the plan view in Fig. 1 *b* it is evident that the E.M.F. induced in the loop by the arriving waves will be proportional to the cosine of the angle α between the direction of the magnetic field and the axis of the coil. Thus, as the coil is rotated in the field of arriving waves, the E.M.F. induced therein passes through successive maxima and minima. The accuracy with which any definite position of the coil may be located depends upon the rate of change of E.M.F. with orientation, *i.e.* the accuracy is proportional to sin α. Thus the determination of the direction of arrival of the waves is most accurate when the signal E.M.F. induced by the waves is zero. All the present-day types of radio direction-finders operate upon this fundamental principle of locating the position of a coil at which the induced E.M.F. passes through a zero or minimum value.

The most important feature which requires attention in the design of a practical direction-finder is the avoidance of spurious E.M.F.'s introduced into the system from one or both of the phenomena commonly known as "antenna effect," and "direct pick-up." The term "antenna effect" is applied to the property possessed by a frame-coil receiver of acting as an untuned vertical aerial as well as a coil for reception purposes. As a result of this, the receiving system may have induced in it an E.M.F. whose phase and magnitude are independent of the orientation of the coil. The signal heard in the telephones will be the sum of that produced by the rotating coil acting as such and that due to the equivalent aerial effect of the whole receiver. As the coil is rotated it is found that the signal zeros become blurred into broad minima only, and moreover, they may be displaced from their correct

* The term "vertically polarised" is used here to indicate that the electric force of the wave lies in the vertical plane of propagation of the wave.

position. The existence of this antenna effect in the system therefore makes the observed directions incorrect, and also makes the determination of these directions more difficult.

Somewhat similar results may be produced by the second of the two causes mentioned above, viz. "direct pick-up." This last term implies that portions of the receiving system, such as the tuning circuits and the amplifier, are getting E.M.F.'s induced in them directly by the incoming waves. These E.M.F.'s will obviously be independent of the orientation of the main receiving frame, and they will be effective in adding to or subtracting from the signal strength finally heard in the telephones. It must be appreciated that while these stray

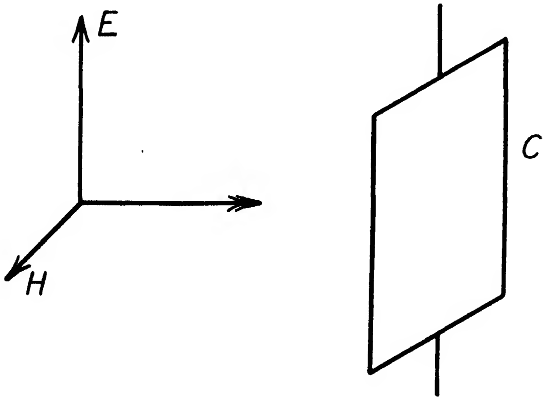

Fig. 1(a)

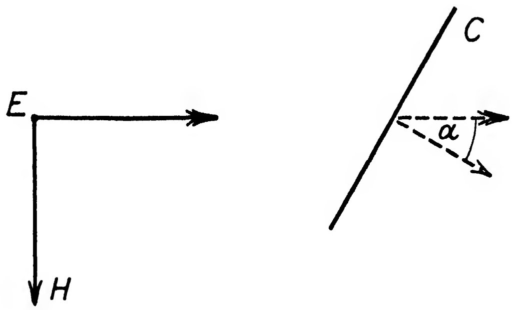

Fig. 1(b)

Fig. 1. Diagrams illustrating the principle of the single frame coil direction-finder

E.M.F.'s may be small compared with the main E.M.F. picked up by the rotating frame-coil in its maximum position, they become of very great importance when the coil is turned into its minimum position.

The methods adopted for overcoming the effects of these spurious E.M.F.'s are based on the use of somewhat elaborate screening arrangements which are described in some detail below. The range of wave-lengths for which the present direction-finder was designed is about 5000 to 20,000 metres and the instrument was required to have sufficient sensitivity for accurate working on transmissions from stations several thousand miles away.

2. Elimination of antenna-effect

While there are several circuit arrangements by means of which the antenna-effect of a frame coil receiver may be compensated for, it has been found convenient for many purposes to overcome the difficulty by adopting an open-wire screen of the type described

by R. H. Barfield. (R. H. Barfield: "Some Experiments on the Screening of Radio Receiving Apparatus," *Journal I.E.E.* **62** (1924), 257.) In this arrangement a whole hut containing the direction-finding receiver is placed within a screen consisting of plane vertical, unclosed loops. These loops are well insulated from each other, from the ground and from the receiver, and care must be taken to ensure that no loop or combination of loops will have any resonance action at the frequency of the incoming waves. The effect of such a screen is that the oscillatory currents produced in the wires by the incoming waves give rise to a secondary electric field within the screen which is sensibly equal and opposite in phase to the electric field of the waves. The difference in phase of the wave field on the two sides of the coil is the quantity which determines the received E.M.F. and this remains unaltered. Thus the signal E.M.F. induced in a vertical frame coil is unimpaired by the

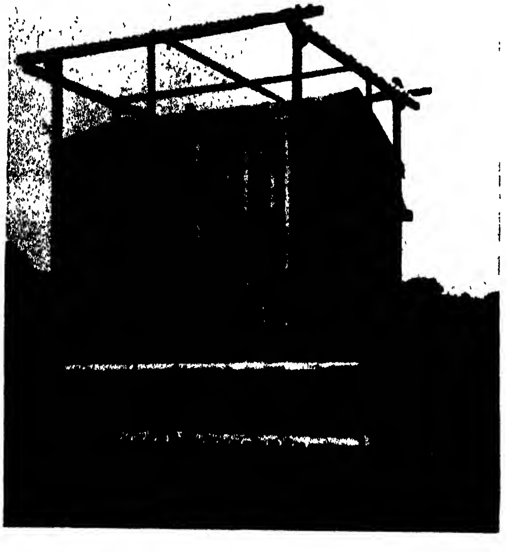

Fig. 2 View of a hut enclosed within an open wire loop screen for reducing antenna effect on a closed coil direction-finder

presence of the screen, whereas no E.M.F. is received on a vertical wire aerial placed within the screen. These facts are easily demonstrated by experiments. A typical hut screened in the above manner and containing a complete direction-finder is shown in the photograph in Fig. 2. Among the advantages of such a screen is the fact that when once it is installed no adjustments or alterations whatever are required for any direction of the waves or their wave-length. Another important feature is that the operator who often materially contributes to the antenna-effect experienced is protected within the screen.

3. Receiving coil connections employed

A schematic diagram of the connections employed in the direction-finder is given in Fig. 3, while a photograph of the complete direction-finder ready for use is given in Fig. 4. The receiving coil intended for use with this set is of dimensions 5 ft. square: the coil shown in the photograph is a temporary one of dimensions 5 ft. by 3 ft. 6 in. The coil itself is of box-shape wooden construction wound with a single layer of 50 turns of insulated copper wire. It rotates about a vertical axis in a wooden frame suspended from the roof of the hut

in such a manner that the scale is at a convenient eye-level for the observer. The scale is so set that true geographical bearings are read off directly. Connections from the receiving coil are taken to a suitable tuning condenser in series with a small coil coupled to a secondary tuned circuit immediately preceding the radio frequency amplifier. Use of indirect coupling in this manner has the combined effect of giving increased selectivity and also of assisting in the reduction of antenna effect. To the secondary circuit is also coupled a coil fed by local oscillations from a separate source for heterodyne purposes, in the reception of undamped wave signals. The extent of the screening involved is indicated by the dotted line in Fig. 3 and its nature can be seen from the photograph, Fig. 4.

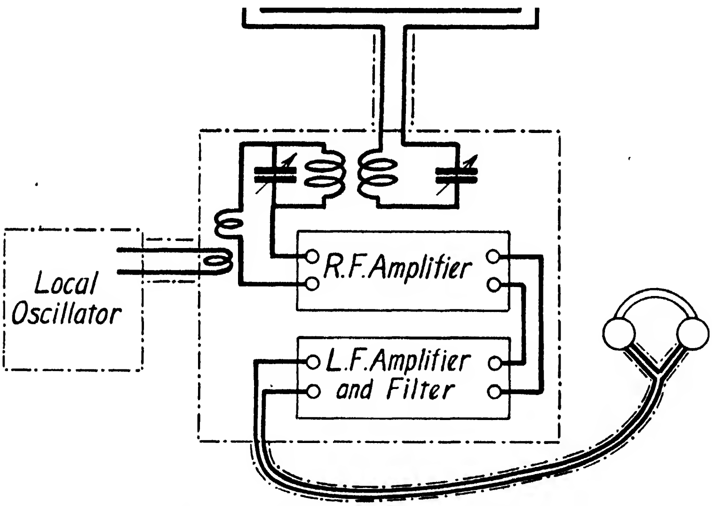

Fig. 3. Schematic circuit diagram of the single frame coil direction-finder. The broken line shows the extent of the screening employed

4. The screened receiver

The whole of the receiving apparatus is contained within a screening box as shown in the photographs in Figs. 4 and 5, the smaller box to the left being the local oscillator similarly screened. The principles underlying the use of such screens and experiments demonstrating their effectiveness have been previously described. (R. L. Smith-Rose: "On the Electromagnetic Screening of a Triode Oscillator," *Proc. Phys. Soc.* **34** (1922), 127–38.) The box used in the present case is constructed of wood, lined inside and outside with tinned-iron sheet, and it is provided with a well-fitting lid with spring contacts arranged on its inside, in the manner shown in Fig. 7. The effectiveness of such screens largely depends upon the quality of the contact made at the overlapping joints, and also on keeping the number and size of holes down to the absolute minimum. It should be mentioned that in this and similar instances the "lid" of the box is purposely arranged at the side since this is the position in which its absence produces the least effect, when considering the un-

desired E.M.F.'s induced directly into the receiver by waves with a horizontal magnetic field. It will be noticed in Fig. 4 that a small sliding door has been arranged in the lid to enable tuning adjustments to be carried out without removing the main lid. The reduction in screening effect when this door is open is quite noticeable by the reception of long wave signals from English high-power stations acting on the secondary circuit within the box. The apparatus inside the box is arranged progressively so that the connections are as direct as possible. Leads from the main frame pass into a vertical brass tube rigidly fixed into the top of the box. The top shelf contains the primary and secondary tuned circuits. Fixed condensers connected to stud switches and variable air condensers for fine adjustment are employed on the tuner panel, and interchangeable coupling coils are provided. These coils

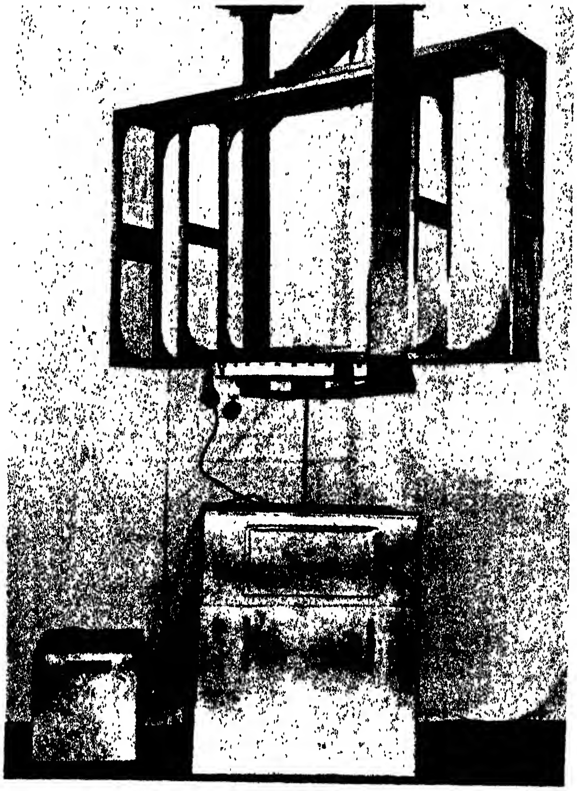

Fig. 4. Photograph of a complete direction-finder ready for operation

are arranged with their turns in a horizontal plane to minimise the E.M.F. directly induced from waves with a horizontal magnetic field. A photograph of the back of the tuner panel showing the disposition of the coils and condenser is shown in Fig. 6. The second shelf of the screened box contains a standard type of radio frequency amplifier. This comprises six stages of resistance capacity coupled amplification followed by a detector valve. In the bottom of the box is placed the three-stage amplifier-filter, comprising two stages of transformer coupled amplification followed by one tuned filter stage. Each of these amplifiers has its own batteries associated with it, and the valve-filament circuits are controlled by tumbler switches at the left of the box, so that the set can be switched in and out of operation without removing the lid.

The local oscillator is of a standard design which has been previously described (R. L. Smith-Rose, *loc. cit.* p. 135); it is provided with external controls and the leads supplying

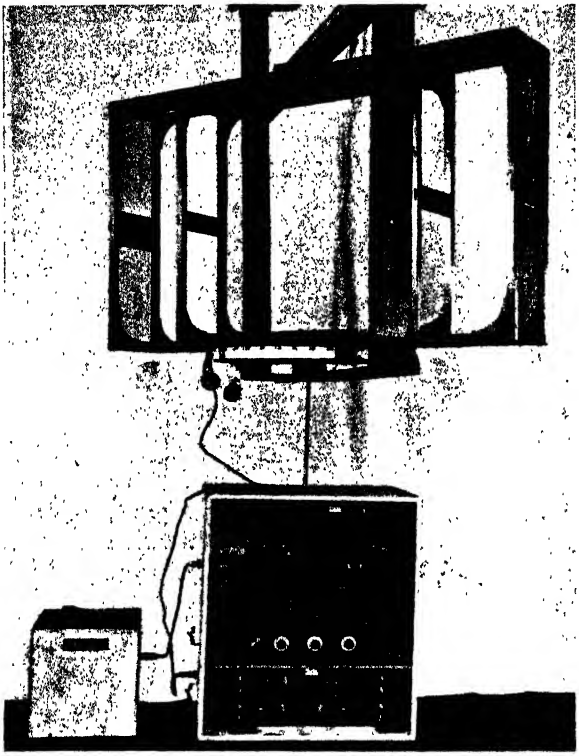

Fig. 5. A view of the direction-finder with the lid of the screened box removed to show details of the receiving apparatus

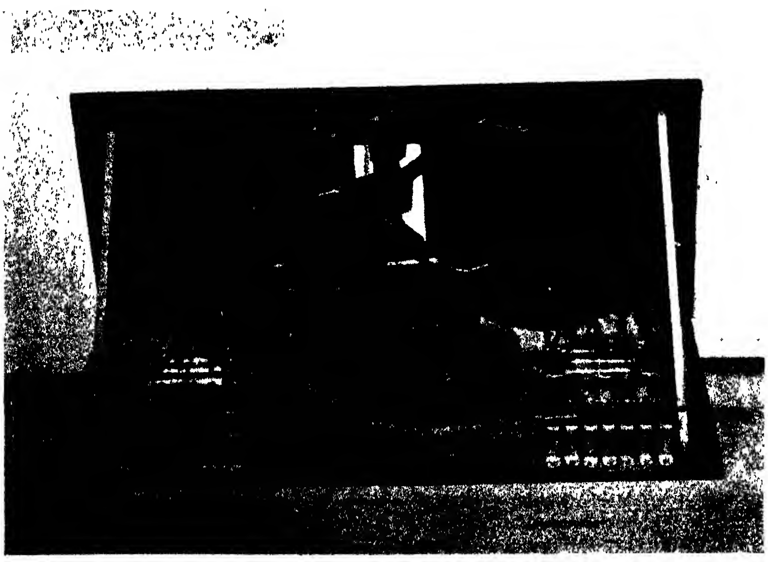

Fig. 6. A view of the rear of the tuner panel showing the inductance coils arranged in horizontal planes

the oscillations to the coupling coil on the tuner panel are screened with a braided copper wire covering. Similar screened wire is used for the telephone leads, the screen being effectively connected to the metallic lining of the box and to the operator's headband.

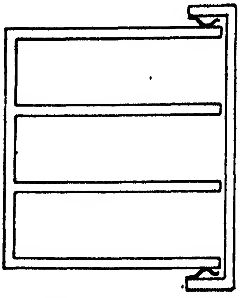

Fig. 7. Sectional diagram of the screened box and lid

5. Amplification and the audio-frequency filter

As already stated, the radio-frequency amplifier is of the resistance-capacity coupled type of a standard commercial pattern. The measured voltage amplification of the six-stages at various wave-lengths is shown by the curve in Fig. 8. From this curve it is seen that over the required range of 5000 to 20,000 metres an overall amplification of from 1000 to 800 is obtained.

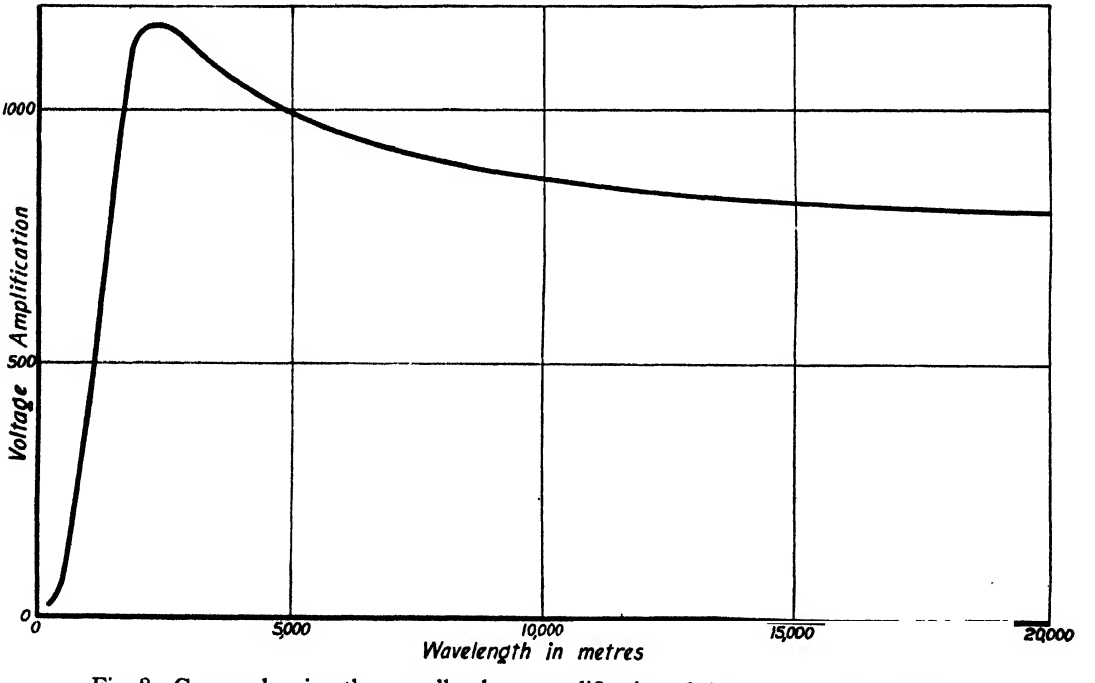

Fig. 8. Curves showing the overall voltage amplification of the 6 valve radio frequency amplifier at wave lengths from 500 to 20,000 metres

In operation an adjustable reaction coil was used on this amplifier, but this was not inserted for the purpose of these measurements. For reception purposes the reaction is adjusted until the decrement of the secondary circuit is approaching the point at which the signals begin to "ring."

Now it is well known that when undamped waves of the order of 10,000 to 20,000 metres

in wave-length (*i.e.* corresponding to a frequency of 30,000 to 15,000 cycles per second) are detected by the heterodyne method, transmissions differing widely in wave-length may produce simultaneously beat notes within the audible range for any one setting of the local oscillator. Further since the usual requirements in this class are to receive some faint

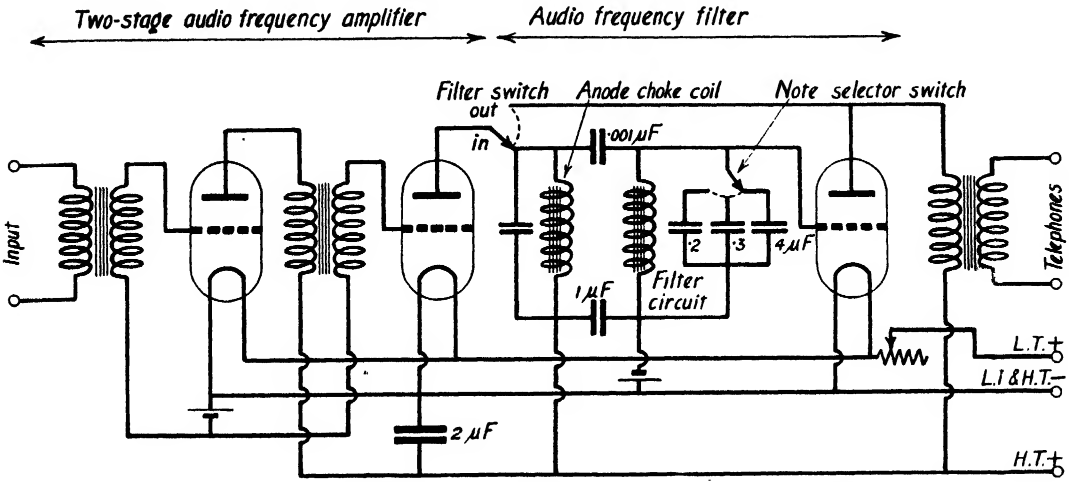

Fig. 9. Circuit diagram of the audio frequency amplifier and filter

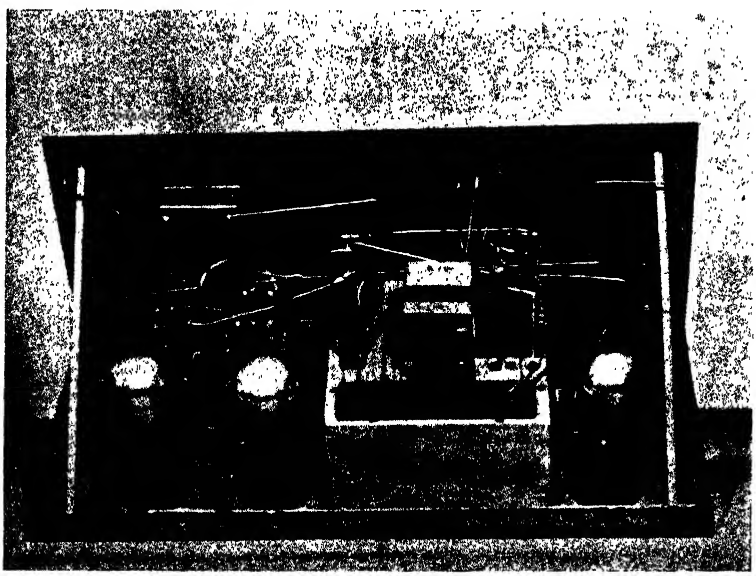

Fig. 10. Photograph of the rear of the audio frequency amplifier and filter showing arrangement of the components

signals from a distant station and simultaneously reject signals on a fairly close wave-length and perhaps hundreds or even thousands of times the intensity, it is usually found that the selectivity obtained at the radio-frequency end of the receiver is insufficient for practical purposes. This effect is exaggerated in the case of direction-finding since the coil is in the minimum intensity position for the signal under observation and may frequently be in or near the maximum position for the interfering signal.

It is, therefore, particularly desirable in a long-wave direction-finder to utilise some filtering arrangement in the audio-frequency portion of the receiver. The arrangement adopted in the present case, similar to that employed in the long-range receivers of the Radio Section of the General Post Office, is shown by the schematic circuit diagram, Fig. 9, while Fig. 10 is a photograph of the back of the audio-frequency-filter-amplifier, showing the disposition of the apparatus. Two stages of ordinary transformer-coupled audio frequency amplification are employed, and the output from the second of these is choke-

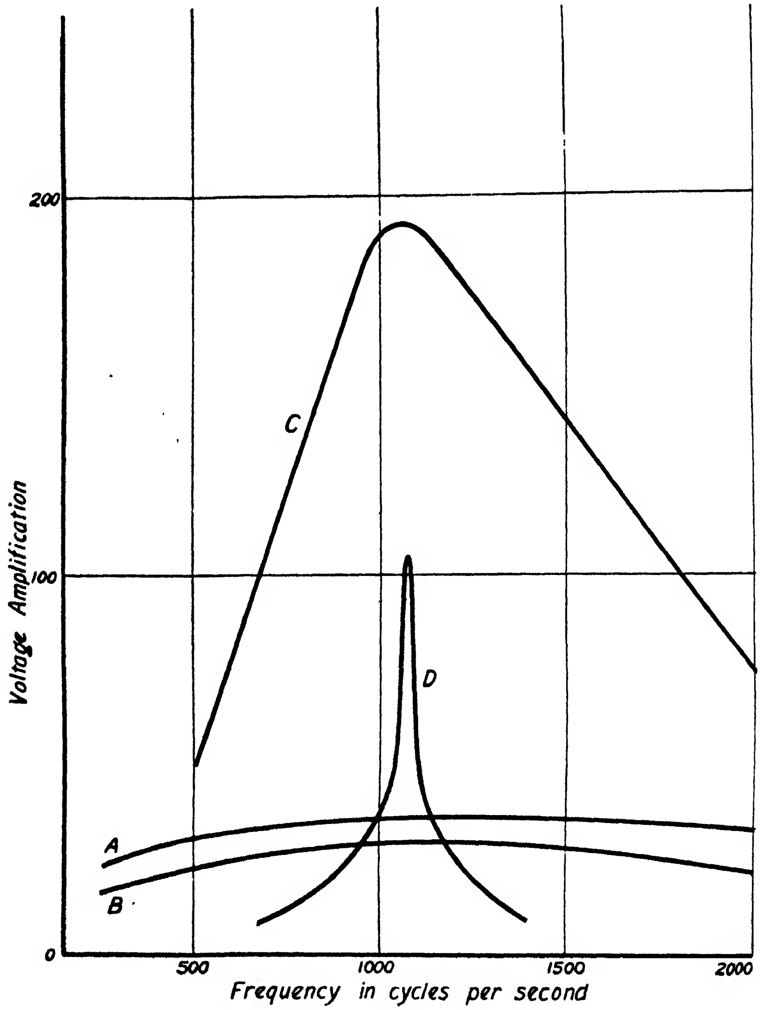

Fig. 11. Curves showing the voltage amplification at various frequencies for the audio frequency amplifier with and without tuned filter

capacity coupled to a third stage. Across the input (grid-filament) circuit is connected a tuned rejector circuit of moderately low decrement. An iron-cored toroidal coil is employed having an inductance of 0·08 henry and a resistance of 4·5 ohms at a frequency of 1000 cycles per second. Three fixed condensers are connected across the coil with a selector switch, so that the resonant frequency of the circuit can be altered. This is of advantage during long observation periods since the ear becomes fatigued when listening to a single note.

The measured amplification curves of the first and second stages separately are shown

at *A* and *B* in Fig. 11. These are seen to give moderately uniform amplification over the range 250 to 2000 cycles. Curve *C* on the same diagram gives the amplification of the second and third stages together with the choke coupling coil tuned to about 1000 cycles per second but with the rejector circuit disconnected. With the rejector circuit inserted curve *D* is obtained; this shows that although some loss in amplification is obtained, the filtering action of the rejector circuit is very considerable. For example, the frequency band width of the curve at the position where the amplification is half the peak value is

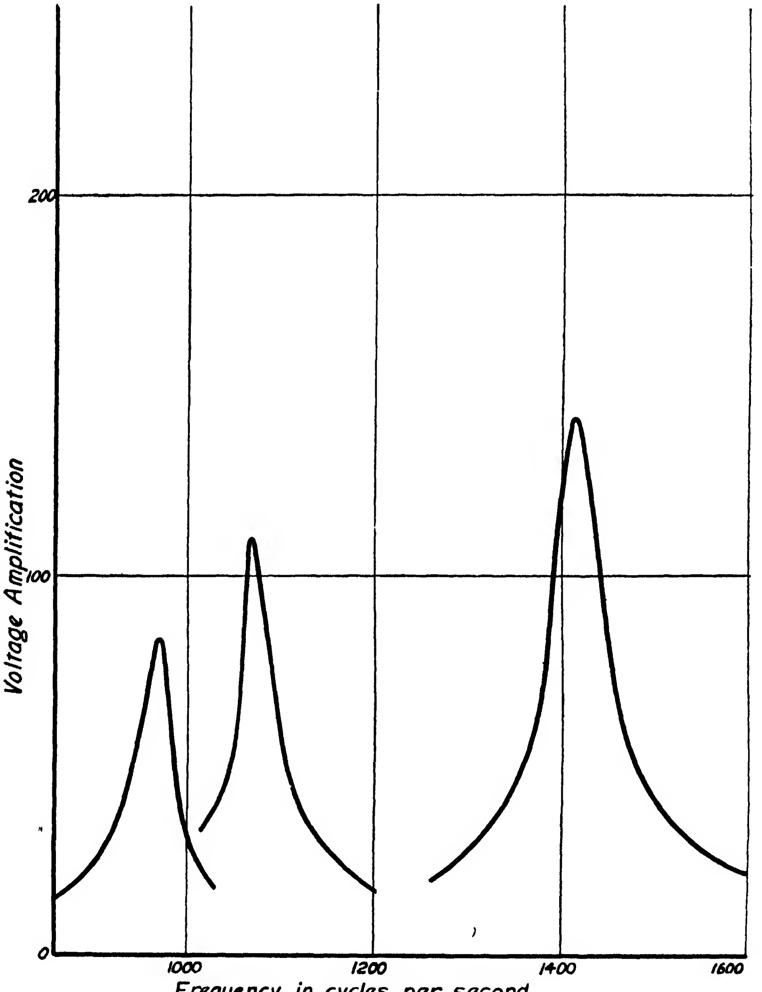

Fig. 12. Voltage amplification curves showing the resonance curves of the combined amplifier filter for the three positions of the note selector switch

only 50 cycles with the rejector circuit inserted as against over 1500 cycles without it. Fig. 12 shows the three curves obtained for each of the three positions of the tuning switch to the filter circuit, illustrating how either of the resonant frequencies, 980, 1070, and 1450 can be obtained. Considering that with the first stage connected the peak voltage amplification will be of the order of 2000 the performance of this combined amplifying-filter is considered to be satisfactory. Reverting to Fig. 9 it will be seen that a switch is provided whereby the third stage may be cut out and so provide the amplifier with a flat characteristic a feature which is very useful for searching purposes on the direction-finder.

The note filter is intentionally placed after the amplifier, so that the effects of any stray fields on the transformers of the amplifier become filtered out. This would also be an advantage if, for example, the input end of the audio-frequency panel had any stray coupling with the later stages.

6. Results obtained

The direction-finder described in this paper was constructed for use in connection with an investigation being carried out for the Radio Research Board established under the Department of Scientific and Industrial Research.

With certain limitations the instrument was found to fulfil the requirements of the investigation, which was to compare the variability of the wireless bearings observed on stations at distances in excess of 1500 miles with those at smaller distances. For the purposes in view many observations have been made on American transmitting stations at distances of three to four thousand miles. Under favourable conditions a bearing observation can be made on these stations with an arc of silence at the minimum signal position not exceeding two degrees. The observed bearing is the mid-point of this arc of silence, and this reading is therefore obtainable to a fraction of a degree. The accuracy of the bearing so obtained and its utility for any purpose depend to some extent on conditions local to the direction-finder, and on other atmospheric conditions. This aspect of the subject, however, has already been discussed in considerable detail in other publications.

The introduction of the filter stage in the audio-frequency amplifier was very successful in reducing the interference from European transmitting stations operating on neighbouring wave-lengths. For example, the interference from the high power transmitting station at Rugby on a wave-length corresponding to 16 kilocycles per second is not serious except when reception is attempted within a few hundred cycles of this frequency. In this instrument, as in all other cases of wireless reception, the limit of utility of the selecting arrangements is reached when the strength of signals becomes appreciably smaller than the intensity of the atmospherics, a feature which varies according to the time of day and season of the year.

NOTE ON THE PRODUCTION OF HALF-SILVERED MIRRORS. This investigation was carried out by H. L. SMITH, B.Sc., F.I.C. (British Scientific Instrument Research Association.)

A number of experiments have been carried out on the formation of half-silvered or semi-mirrors.

(1) Solutions as used for full mirrors, using invert sugar as the reducing agent, did not give promising results. The time of silvering and the concentrations of the solutions were varied. The results were usually patchy and of poor colour.

(2) In this series of experiments a 4 per cent. solution of silver nitrate was used. For each test 25 c.c. were taken and ammonia solution was then added until the precipitate which is first formed was redissolved. A few drops of silver nitrate solution were then added so as to make the solution faintly opalescent. Finally, water was added to make the solution up to 50 c.c. The glass was immersed in this solution and then varying amounts of one of the following reducing agents dissolved in water were added.

Invert sugar,	Quinol,
Chloral hydrate,	Sodium hydrosulphite,
Formaldehyde,	Hypophosphorous acid,
Chloral and formaldehyde,	Invert sugar and formaldehyde,
Amidol,	Invert sugar and chloral hydrate.

Of these only two gave results of any promise. One was a mixture of 5 c.c. of a 10 per cent. solution of chloral hydrate with 5 c.c. of formalin. From 0·5 to 1 c.c. of this mixture added to the 50 c.c. of the silver solution gave some fair results, but the mirror always exhibited two colours by transmitted light; there was a trace of pink as well as a purplish blue colour.

The other reagent gave better results. A sugar solution was made up as follows:

Cane sugar	5 grams.
Water	50 c.c.
Tartaric acid	0·6 gram.

These ingredients were boiled together for 10 minutes and allowed to cool. To the cooled solution were added:

Alcohol 10 c.c.
Water to make a volume of 100 c.c.

This solution is one which has been used with success for full mirrors. A mixture of 2 to 3 c.c. of the sugar solution with 2 c.c. of a 10 per cent. solution of chloral hydrate was used as the reducing agent.

(3) Glycerine with and without formalin did not give promising results. With glycerine alone some very good full mirrors were obtained but it is slow in action.

(4) Very dilute solutions were used, formaldehyde being the reducing agent.

Silver nitrate solution N/10 5 c.c. were diluted with 80 c.c. of water. To this were added 5 c.c. M/1 solution of formaldehyde and 2·5 c.c. of N/5 ammonia solution. This was tried also in greater concentration up to double the strength but no satisfactory results were obtained. The silver was precipitated as a powder or in patches and was not coherent.

(5) A member of the British Scientific Instrument Research Association, Messrs Adam Hilger, Ltd, placed at our disposal the details of a method which has been found to give satisfactory results. When every precaution was taken to follow the exact instructions, especially as to the cleaning of the glass, and when good distilled water was used for the final washings, both before and after the silvering process, good results were obtained.

Four solutions are necessary:

A. A 10 per cent. solution of silver nitrate.

B. Formalin (formaldehyde 40 per cent. solution).

C. Sugar 400 grams.
Alcohol 200 c.c.
Nitric acid 10 c.c.
Distilled water to 2000 c.c.

The sugar is to be dissolved in some of the water, the acid and the alcohol added and the volume made up to the required volume. The solution is allowed to stand two weeks before use.

D. Chromic acid 250 grams.
Dilute sulphuric acid 1500 c.c.

The glass to be silvered is placed in a dish and cleaned with (1) strong nitric swabbed over the surface by a small wad of cotton wool fixed on a glass rod and (2) by allowing the glass to stand in solution D for five minutes. It should then be well washed in running water and finally rinsed in distilled water.

Take 20 c.c. of solution A, add ammonia solution until the precipitate which first forms is just redissolved. Then add a little silver nitrate solution until the liquid is faintly opalescent and make up the volume of the solution to 100 c.c. with distilled water.

The reducing solution is made by mixing 5 c.c. of solution B with 5 c.c. of solution C.

The process is carried out as follows: The glass is suspended, with the face to be silvered either upwards or downwards, in 100 c.c. of the ammoniacal silver solution. The reducing solution is then added and the liquid kept moving until it becomes reddish in colour. It is essential that the liquid be kept moving. This red colour is very transient, the liquid rapidly becomes dark. As soon as the reddish colour is noticed the liquid is poured off and a second quantity of 100 c.c. of the ammoniacal silver solution is added without any reducing agent. The glass is allowed to remain in this solution until the required amount of silver is deposited. The time required is a few minutes but will vary according to the temperature. The mirror is finally rinsed well in distilled water and allowed to dry in the air.

HERBERT JACKSON.
Director of Research.

BRITISH SCIENTIFIC INSTRUMENT RESEARCH ASSOCIATION.
June, 1925.

THE PROCEEDINGS OF THE OPTICAL CONVENTION, 1926*

It is rather interesting to take down from the bookshelf the *Proceedings* of the two previous Conventions of 1905 and 1912 in order to compare them with the imposing two-volume edition of the Convention of 1926; then, when some attempt has been made to appraise the contents of these books, we may ask ourselves a short but important question: "1933?"

It would be folly to judge this collection of papers by the ordinary standards applied to scientific papers, for these have partly been written in response to invitation, although the larger proportion contain new and original matter. The fact that ninety-four articles were contributed is in itself remarkable because the existence of publications like this *Journal of Scientific Instruments*, the *Transactions of the Optical Society*, and others, might have been expected somewhat to lower the potential of the sources of supply. That so many contributors, working in different fields, were able to meet on the common ground of "Optics" and to discuss each others' difficulties and problems was one of the most valuable features of this last Convention. For example, the comments of an astronomer on the feasible accuracy of angular measurements with theodolites (vol. II, p. 633) might well be taken as a basis for serious thought.

The strenuous work of the Papers Committee, under the chairmanship of Mr T. Smith, has, then, produced a remarkably varied and interesting set of papers. No doubt there is a great deal of merely ephemeral interest; some authors, and contributors to discussions, suffer from verbosity, so that it is questionable whether such unrestricted printing should be contemplated on a future occasion, but these defects bear no proportion to the merits of the collection, which comprises two books of reference indispensable for all those interested in the modern application of optical science. It would be impossible, within the limits of a short review, to comment upon all the subjects dealt with in the papers; we shall restrict attention to a few of these in a way which will perhaps serve to indicate the general scope. The Presidential Address gives an admirable summary of recent optical activities in this country, and includes an historical section dealing with the development of astronomical optical instruments; it is well to be reminded of the stimulus that astronomical endeavour has always been in the development of optics, nay! of science generally.

* *Proceedings of the Optical Convention*, 1926. 2 vols. quarto, Part I, 512 pages; Part II, 578 pages. Illustrated with plates and figures in the text. The Optical Convention, 1, Lowther Gardens, Exhibition Road, London, S.W. 7. Price £3. 0*s*. 0*d*. net.

Theoretical physical optics (excluding the theory of optical systems) is represented only by two papers, that of Prof. Lindemann on the divergence between the electromagnetic and quantum theories of light, and that of Mr E. T. Hanson on the theory of total reflection. It is unfortunately true that the present theoretical account of total reflection is somewhat obscure. Is it possible that a new and careful study of such phenomena may be of assistance in building the bridge of thought between those modes of energy propagation with which we are mechanically familiar, and those which seem to involve entirely new features; or is the wave theory as adequate as it seems?

The first volume is mainly devoted to colorimetry, photometry, and ophthalmic optics. J. Guild contributes a most useful survey of modern developments in colour measurement; careful attention is given to the question of the standard source of light, the phenomena of the visual sensations, and the practical details of instruments. It is clear that the next step in colorimetry must be an intensive study of the physiological phenomena of colour vision; until adequate knowledge of the "sensation curves" and their variations with the luminosity level is forthcoming, visual colorimetry will still be uncertain, and physical colorimetry next to impossible. This survey will make the paper by Barker and Hirst, on "Colour problems in the Woollen and Worsted Industries," doubly interesting; other papers discuss the colour problems in regard to printing inks, and the peculiarities of selective absorption. Houston and Peddie describe new instruments for the investigation of colour vision, and, as a contrast to the apparatus purely concerned with scientific aims, the "Theatre Mutochrome" seems to offer infinite possibilities of development if the troubles connected with the necessary intensity of the source of light can be overcome.

There is a noteworthy development at the present time of a *rapprochement* between the various workers approaching such problems as those arising in the study of colour from various standpoints; physiologists, psychologists, and physicists alike are finding the benefits of mutual intercourse. It is much to be wished that a similar co-operation may be intensified in the realm of ophthalmic optics, which, of all the subjects dealt with, is perhaps the most important, both from the points of view of human welfare and of the optical trade. The papers contributed in this section give no indication of many of the numerous instrumental problems which are being faced at the present time in the country, and the various professional jealousies which hinder a meeting on the common ground of science are wholly to be deplored. This is said in a spirit by no means critical of the dozen or so papers which are printed. Statistical studies of defective vision, and enquiries into the influence of illumination upon visual acuity, do indicate a welcome interest in the problems of the safeguarding of eyesight.

The rapid development of "physical" methods is naturally reflected in several of the papers contributed on the subject of photometry. E. A. Baker deals with the difficult subject of the validity of the photographic integration in the case of the photographic plate when a rotating sector is employed. It seems, however, extremely undesirable to bring the mention of "Talbot's law" into the title of the paper, for Talbot's *law* is simply and solely concerned with vision and was never intended to convey any general property of intermittent illumination produced by a sector. While the work described is valuable so far as it goes, it is by no means sufficiently general. The 1922 work in this connection cited in the discussion probably did not involve photo-electric density measurements, and in view of the convenience of photographic methods in certain cases it would be highly interesting to see what results would be given by a thorough investigation. Photo-electric methods in photometry are discussed by Harrison, and by Campbell and Freeth. It seems clear that the use of these cells in "substitution methods" for photometry, spectro-photometry, and densitometry has come to stay, with a distinct improvement in accuracy as compared with visual methods; it will probably be some time, however, before visual methods are displaced

for general and casual work; but in the large standardising and testing laboratories, where all the photometric work of any importance is carried out, a tremendous amount of time can be saved by the adoption of physical methods. It seems that Mr Haigh would have obtained spectro-photometric results of more direct significance if he had used a monochromator or some arrangement to give more homogeneous light; nevertheless the experiments completely justify the physical method in this somewhat exacting measurement on glass.

To those who care for historical instruments, the noteworthy collection on view at the Convention made a great appeal. One very interesting microscope objective, a $\frac{1}{8}$ in. by Ross* (made about 1851?), possesses a front lens of fused quartz; this is the first time this interesting material had been used. It is to be hoped that the optical homogeneity of the specimen was better than some of those made in much more recent times, but perhaps the making of good fused quartz is a lost art! The historical side of instrumental optics is represented in the *Proceedings* by interesting articles contributed by Clay, Whipple, Baxandall, and Court.

There is no finality in optical design; the attainment of a new standard of transparency in optical glasses challenges the optician to supply the astronomer with instruments of greater speed for astronomical photography; as H. Dennis Taylor shows, there are distinct possibilities of progress, and the modern optician cannot afford to rest on his laurels. His traditional methods of lens production have been modified by the employment of new types of grinding machinery, just as the simple lathe has lost some of its old-time pre-eminence in his machine shop. William Taylor describes such changes in a most interesting manner. Then, too, the optician must always be on the alert to study and anticipate the needs of the user; he is surely favoured when users of surveying instruments from Canada and India take the trouble to write a summary of their requirements. The user, however, is a pampered person; he even makes the same complaint which is frequently made by ladies who purchase a garment of exceptional durability!

There can be no doubt, however, that a surveyor's time can be saved enormously by suitable instrument design, and the present trend of development is toward this end. There seems to be some tendency towards the introduction of instruments in which the accuracy of the results is more than ever dependent on the accuracy of the makers' adjustments, as in cases where "reversible" bubbles and "constant" bubbles are employed; the makers' reputation is *all important* here, but on the other hand, there are time-saving devices, like the double-reading micrometer in its various forms, which merit a great deal of careful attention.

How far has finality been reached in the theoretical side of optics? T. Smith's interesting review of lens theory indicates the tremendous stimulus which considerations based on the wave nature of light have had on the practice of lens design. He comments on ray-tracing methods and rightly emphasizes the desirability of using a special system adapted for the method when machine calculations are made; but apart from the relative cost of a calculating machine as against a table of logarithms, which will decide the question for many, the chief possible advantage of the machine is in the factor of speed. If, however, a really sufficient account is kept of the various steps of the calculation, the speed factor is discounted, whereas in logarithmic work every step *must* be written down. Careful logarithmic work embodies a system of check calculations which always attain the optimum accuracy. It is by no means the case that machine methods enjoy an unchallenged superiority, even in speed. It would be interesting, by the way, to know the origin of the usual standard trigonometrical formulae used by Bessel and Seidel, and when they were first used.

* The list of Ross' objectives given by Nelson, *Jour. R. Mic. Soc.* 1900, p. 434, mentions a $\frac{1}{8}$ in. of 1851.

Buxton and Steward both contribute papers on the diffraction patterns associated with aberrations. A great deal more information on the effects of *coma* and *astigmatism* would be very useful, but already our knowledge of the fundamental nature of the optical image under aberration is immensely greater than was the case a few years ago; some of the work done along these lines at the Technical Optics Department of the Imperial College in the study of measurement of aberrations is described in papers contributed by research students of the College.

While analytical theory is still useful in the rough design of telephoto lenses, we learn that trigonometric trials are the only hope (at present) in the advanced stages of the design, and also with the high aperture photographic lenses described by Lee; it seems, indeed, that the distortion, apparently incurable in a telephoto lens as viewed in the light of the approximate theory, can in practice be avoided. Dowell's description of the universal lens interferometer shows how all kinds of photographic lenses, including "telephoto" types, can be accurately tested in terms of the fundamental criterion of optical path.

Then, too, we are reminded by several papers of the other sides of optical design; the mechanical principles of an interesting interchangeable nosepiece for the microscope are described by Pollard, and we find that improvements are still possible even in such familiar instruments as a photo-measuring micrometer, or a spectrometer. Although the microscope is familiar enough we find again that its accessories, and even the conception of the necessary accuracy and sensitiveness of the mechanical parts, are now in a changing condition. Beck's paper gives a picture of some sides of development, and more contributions on this topic would have been of interest. We see how the question of the *illumination* has advanced into its present position of primary importance, and how considerable advances have been made within the last few years.

Though the selenium cell is not at present in favour for photometric purposes, some of its possible uses are illustrated in a paper on physical fringe counting methods by Fournier d'Albe and Symonds, and another on optical problems relating to speaking films by Rankine; these papers take us into the fascinating realm of optical invention, which is a mine yet unexhausted, although the more obvious nuggets have been already taken.

We have done little more than skim the surface of things in this very hasty mention of some of the topics called to mind in turning the pages of the *Proceedings*, but it will be evident that the scope of these papers is a very wide one. It should be clear that Optics is a subject which is by no means played out, and indeed there are many problems for investigation which will be evident to the careful reader; if sufficient interest is aroused to lead to new researches by fresh workers the Convention will be indeed successful.

After perusing some of the articles, the feeling will grow on the reader that considerable advances may be expected from the closer union of physiological research and instrumental optics; we may expect some drastic alterations in the familiar forms of instruments when the principles of geometric design are more widely used; physical methods will replace visual methods in photometric and colorimetric measurements; increased facility in the use of radiation other than visible (and the development of suitable optical systems) will give valuable results in astronomical photography and microscopy; all-round improvements due to greater refinements in materials, design, and manufacture will be made in many instruments; most certainly the optical theory and practice now current in physics courses will have to be revised (and the sooner the better); other vast possibilities of progress (but not within sight at the present time) are bound up in the development of grinding and polishing processes for the automatic production of required non-spherical surfaces.

It is indeed fascinating to speculate on the probable situation in 1933!

L. C. M.

CORRESPONDENCE

ERRORS IN LEVELLING STAVES

THE note on errors in levelling staves in the April number of the *Journal* (p. 234) prompts one or two remarks. Such errors are due to either (1) a change in length in the staff, or (2) incorrect graduation. A wooden staff alters its length with change of temperature, but even more according to the moisture absorbed in the wood, and may vary 0·005 ft. in 10 ft. from this cause. Whether this is serious or not depends on the class of work for which the staff is used. The method of standardizing the staves given in the note refers only to errors in graduation, and is a method that was adopted by the Ordnance Survey some 15 years ago for standardizing or checking staves. At that time really accurately graduated staves were not obtainable in the market.

Papered staves are bound to be inaccurate, but why have them papered, or even painted or stencilled, when they can now be obtained with the graduations accurately cut on wood or invar? These can be checked at the N.P.L. if required, and no corrections to the readings should be necessary; correcting the readings for known inaccuracies in the graduations entails considerable office work, which costs far more than the slight extra cost of the accurate staves. If the variation in length (error 1 above) is important for the work in hand, it is necessary in any case to have a continual check on the total length of the staff, and in this case it is simplest and cheapest to have the divisions cut direct on invar.

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REVIEWS

Handbuch der Physik. Band 2. Elementare Einheiten und Ihre Messung (Berlin, Julius Springer), 1926, Reichsmark 39, 60. Gebunden Reichsmark 42. Pp. vii + 522. 1926.

This volume gives an account of the methods of measurement of length, angle, mass, volume and density, time, velocity, pressure and gravitational force, to each of which a chapter is devoted.

A final chapter discusses the definitions and experimental estimation of universal physical constants. Each subject is treated by a specialist, and in accuracy, clarity of description and completeness the book is excellent; the illustrations in particular combine the best features of the simplified diagrams of elementary textbooks with those of the extracts from working drawings which frequently cast obscurity upon the subject-matter of technical volumes: as an example, the drawings of escapements in the discussion of pendulums could hardly be improved.

The section on the measurement of short intervals of time, by Cranz, whose original investigations on this subject are well known, is of special interest from the beauty of the methods and the refinement of technique.

Much material has been brought together for the first time in the description of velocity measurements for solids, liquids and gases, and the principles which are common to these widely different applications are clearly brought out. This feature indeed, is of necessity characteristic of a book whose arrangement, being fixed by measurements rather than by properties of matter, results in paths being opened up which continually intersect the main roads of scientific description.

Ample space is given to the modern methods of measuring low pressures developed by Knudsen, Langmuir and Hull. This is followed by a section on high pressure referring chiefly to research on explosive action.

The value of the book is enhanced by the numerous references and by the summary given in the last chapter.

R. T. B.

Practical Physics. By T. G. Bedford (Demonstrator in the Cavendish Laboratory, Cambridge). Published by Longmans, Green & Co., Ltd. Pp. 425. Price 10*s*. 6*d*. net.

There are so many text-books of practical physics already in existence that one may perhaps be pardoned in asking "Why add to the list?" Mr Bedford's book, however, provides its own answer. It covers a wide field in a very efficient manner and is intended, as the preface makes clear, to supplement and not to replace oral instruction.

Much sound advice is given to the student regarding methods of making observations, order of accuracy and the care in handling delicate (and often expensive) instruments.

In addition to much useful explanatory matter, descriptions are given of 151 experiments, divided as follows: I. Mechanics and Properties of Matter (35 experiments); II. Heat (28); III. Light (40); IV. Sound (9); and V. Magnetism and Electricity (39). At the end of each section additional exercises are introduced to test the student's grasp of the subject.

The experiments are well chosen and, perhaps with the exception of the section on Sound, are well-proportioned in the respective sections. The chapter on Sound is rather short and stereotyped in subject matter. The author need only read Sir Wm. Bragg's *World of Sound* to receive inspiration for new experiments in this so-called, but erroneously so-called, "played out" subject.

The book as a whole is well conceived and should prove very useful to both teachers and students.

A. B. W.

Tungsten. A Treatise on its Properties and Applications. By Colin J. Smithells, M.C., D.Sc. (London: Chapman & Hall, Ltd.) Pp. 167 + viii. 21*s*. net.

Metals may be divided roughly into three classes; those which have been known from time immemorial, such as gold, iron, etc.; those which were discovered in historic times, e.g. nickel and zinc; and those which have been discovered, or at any rate have been produced in sufficient quantities to be of industrial value, within the last century. Tungsten falls into the last group, the metal having been isolated in 1782 by Bergman.

Like many other metals, however, it remained more or less of a chemical curiosity for many years. Indeed, it was not until about 1850 that it first assumed industrial importance, being then employed in the manufacture of special steels; and it was not until nearly 50 years after this that the metal itself came into commercial use in the manufacture of filaments of electric lamps. For some time before this tantalum had begun to displace the carbon filament, of which the early incandescent electric lamps were made, but its use was of comparatively short duration, as tungsten was found to be a much more suitable metal when the difficulties of producing it in the form of wire had been overcome.

In the book under review Dr Smithells deals very fully, and in an admirably clear manner, with the preparation of tungsten from its ores and the manufacture of the metal in the form of wires. He then proceeds to the metallography of the material and describes at considerable length the fascinating study of grain growth in different tungsten wires, a study to which he himself has contributed in no small measure. This part of the book is illustrated by a copious number of excellent photomicrographs. Particular attention must be drawn to the illustrations of polished sections of tungsten spirals, showing the effect of grain growth—both "exaggerated" and "restrained"—in coiled tungsten filaments. The technique necessary to obtain such photographs is of a very high order. The study of materials which can be added to the filaments to restrain grain growth is of great importance in the manufacture of electric lamp filaments, as exaggerated grain growth causes a shortening of the life of the lamp.

The remainder of the book deals with the properties of tungsten and its industrial applications, of which doubtless the most important is the manufacture of iron-tungsten alloys, which are used for the making of high speed cutting tools and for permanent magnets. The chemical and spectroscopic methods of determining the impurities in the material are discussed in the final chapter.

The book is altogether to be recommended as a clear and concise treatise on a subject which is not only of considerable commercial importance but also of very high scientific interest.

J. L. H.

High Vacua. By G. W. C. Kaye, O.B.E., M.A., D.Sc., F.Inst.P. (London: Longmans, Green & Co., Ltd.) Pp. 175. 10*s*. 6*d*. net.

In the preface the author states that "this book had its origin in a course of Cantor Lectures delivered by the writer at the Royal Society of Arts in 1926. It is hoped that the work may prove of assistance and interest to those who have occasion to employ high vacua, whether in research or industry." In its main purpose the book certainly succeeds, for it is interesting and easily readable, and should commend itself to all who are engaged in the production of vacua, whether for research or industrial purposes.

During the past few years considerable numbers of books have appeared dealing with this subject. The production and measurement of high vacua have recently acquired great importance in industry and research; we have only to consider the enormous number of vacuum and gas filled lamps, radio-valves, X-ray tubes, etc. manufactured commercially in this and other countries to realise the growing importance of vacuum practice. In research also, e.g. in the study of radiation and the structure of matter, progress has been largely dependent on means for the production of high vacua. The cathode ray oscillograph, the only oscillograph free from inertia, is a recent development of high vacuum practice likely to prove invaluable to electrical engineering.

The justification for yet another book on vacuum technique is therefore fairly well established. The present small volume by Dr Kaye deals with every branch of the subject from the earliest times to the present day. One might wish for a more extensive treatment, dealing more with principles rather than particular designs, but in such a small compass the author has done well to include so much information. The first three chapters are in the nature of a history, dealing with early forms of vacuum pumps and the general features of electric discharges in vacuum tubes. Then follow chapters on vacuum technique, metal-to-glass joints, backing pumps, high speed pumps, absorption methods of exhaustion, high-vacuum gauges and the measurement of pump speeds. The chapters on metal-to-glass joints and high vacuum gauges should be of particular value to many research workers. Modern industrial procedure and the use of "getters" is dealt with in an interesting manner, but leaves one wishing for further detailed information—this applies more especially to the chapter on absorption methods of exhaustion. The "getter" problem is a very important one, and is vital to all vacuum processes where a highly evacuated enclosure is to be permanently sealed off from the vacuum pump.

To those who have spent long and tedious hours with a hand-operated Töpler mercury vacuum pump there comes a feeling of relief on viewing the present day array of automatic high vacuum pumps which Dr Kaye's book brings before us.

A. B. W.

The Practical Electrician's Pocket Book, 1927. (S. Rentell & Co., Ltd.) Pp. 602. 2*s*. 6*d*. net.

The nature of the contents of this pocket-book, now in its twenty-ninth year of publication, is indicated by the title, the most detailed sections being those of direct interest to practical electricians —e.g. wiring, fault testing, armature repair.

The book is chiefly descriptive, the amount of numerical data being comparatively small. It starts with sections dealing, very briefly, with units, wire resistances, simple measurements and prime movers. Next come electrical plant, dynamos, D.C. motors and control gear, and A.C. machinery; after this electric traction, followed by short descriptions of some electrical workshop tools and the use of electricity in coal mines and for pumping. Short sections on costs and power factor correction precede some 60 pages covering electrical distribution and installation. This latter includes cables, insulating materials, fault localization, fuze rules and regulations. Electrical instruments follow, with sections on the measurement of insulations and of conductor resistance. After meters, switchboards and automatic protective gear we come to primary and secondary batteries, bells, electro-plating and simple telephones. Railway signalling and communication apparatus receive considerable attention, as do motor car lighting and ignition.

Electric lighting is dealt with in considerable detail. Modern wiring systems come next, and though most of them are described quite briefly, steel conduit is dealt with at length. The section on the control of lighting circuits gives a number of useful switching circuits. Heating and cooking are followed by a very practical section on cinematograph working. Pyrometers are dealt with very briefly, and one electric clock system is described in some detail.

S. J. W.

Manual of Meteorology: Vol. I, Meteorology in History. By Sir NAPIER SHAW, with the assistance of ELAINE AUSTIN. (Cambridge University Press, 1926; pp. xx + 339.) Price 30*s.*

This volume is a worthy companion to the one issued some time ago (vol. IV). It is clear that the whole manual, when finished, will be a masterly exposition of a subject which Sir Napier Shaw has made so very largely his own. The present volume is, as its title indicates, mainly historical in nature. It shows the development of meteorology from the earliest times to the present day, the first eight chapters being a most interesting account of the stages through which the subject passed before it established any claim to be regarded as a science. The next six chapters deal in turn with the development of different branches of the science and of the tools, instrumental and mathematical, which modern meteorology employs. The final chapter is devoted to a brief sketch of meteorological theory in history.

There is often a tendency for specialists in science to ignore the lessons of history and to fail to realize the stages through which their subject has passed under the hands of the greater workers of past centuries. It is clear that this failing would receive scant sympathy from Sir Napier Shaw, and his book will make it both a pleasant and a comparatively easy task for the meteorologist to trace the development of his subject almost from the beginning of historical records.

An excellent index completes a book which reflects the greatest credit on all concerned in its production. The demands on the printers' art have not been easy to meet, but the general style of the book both inside and out is well up to the high standard which is now universally associated with the Cambridge University Press.

J. W. T. W.

Beyond the Milky Way. By GEORGE ELLERY HALE. (New York and London: Charles Scribner's Sons, 1926; pp. xv + 105, with 44 illustrations.) Price $1.50.

This book is the third of a series of non-technical accounts of recent progress in astronomy which Dr Hale has written during the last few years. As in the case of the earlier books, the author has dealt mainly with the astronomical work of the Mount Wilson Observatory.

The first chapter deals with the oriental history of the telescope, and gives a summary of the development of observational astronomy before the invention of the telescope. There is an interesting description of the transit instrument made by Tutenkhamen "with this two hands" and recently found in his tomb. The second chapter treats of the heat radiation of stars, and shows the importance of the pioneer work of Nichols, which, with the improvements effected by Coblentz, Abbott and others, has provided so much valuable information for the construction of the life-histories of the stars. The latter portion of the chapter deals with the application of some of the most modern of modern physics to astronomy.

The third chapter gives the book its name, and contains a fascinating account of recent speculation regarding the spiral nebulae, which, it seems likely, are "island universes" lying in remote space far beyond the limits of our galactic system.

The writing of non-technical science is an art in itself. Dr Hale is a master of that art, and we can imagine no mind so dull or so sophisticated that it will not be pleasantly enthralled at his wonderful story of the efforts of modern science to unfold the secrets of the stars.

H. B.

Transactions of the Optical Society

IN vol. XXVII, No. 5 of these *Transactions* Prof. M. von Rohr gives an account of some of Fraunhofer's work and discusses its present-day significance. This account is based on Fraunhofer's own papers, contemporaneous descriptions, and recent detailed measurements of his telescopes. It is shown that in the making of telescopes he obtained results which were markedly superior to those obtained by English opticians, in particular J. Ramsden and the firm of Dollond. This was due to his application of scientific methods of measurement, testing, computation, and glass-making.

The number contains a discussion on colour terminology which took place during the Session of the Optical Convention, 1926. The first portion is devoted to an account by J. Guild of a questionnaire on colour terminology which was issued by the Optical Society of America to elicit information

as to the most popular usages of various words to denote the different attributes of colour. The results of the replies are then discussed.

T. Smith contributes three papers entitled "The Stationary Value of Axially Symmetric Functions," Part I, "The Treatment of Reflection as a Special Case of Refraction," and "On the Light Transmitted and Reflected by a Pile of Plates," and D. S. Perfect shows that direct experimental evidence has been obtained that the transmissive factor of the suface separating two media is unaltered if the direction in which the light travels is reversed.

In vol. XXVIII, No. 1, R. Kingslake investigates the possibility of analysing mathematically the interferometer pattern produced by a lens, in order to obtain a measure of the aberrations from the coefficients of the terms in the various orders of x and y, the coordinates of a point on the interferogram whose optical path difference relative to the central ray is known at once by counting the fringes. The results obtained do not agree very closely with those obtained for the same lens under identical conditions by the oblique Hartmann test. Possible reasons for this disagreement are suggested.

J. W. T. Walsh and W. Barnett discuss the effect of slightly selective absorption in the paint used for photometric integrators. The paper describes a theoretical treatment of the problem and gives a simple method for calculating the magnitude of the effect in the case of sources having a spectrum approximating to that of a black body. The method has been tested by photometric measurement and a satisfactory agreement between theory and practice has been found. It is shown that in work on normal type electric lamps to an accuracy of 1 to 2 per cent. a quite noticeable coloration of the light may be produced by the sphere (either on account of paint or window selectivity or both) without the necessity for making any correction to the measured values of candle-power.

A simple and accurate method of finding the positions of the foci of different zones of microscope object glasses is described by Conrad Beck. It consists essentially in placing a diaphragm with two slit apertures behind the object glass to be tested, the directions of the slits being at right angles to one another, and finding the position where the images form a symmetrical cross.

J. A.

TABULAR INFORMATION ON SCIENTIFIC INSTRUMENTS

By an oversight which is greatly regretted, the table of Hot-Wire and Thermo-Junction Voltmeters and Ammeters which was published in the last number did not include the instruments of the Cambridge Instrument Co., who have now kindly contributed the following particulars.

XIX. HOT-WIRE AND THERMO-JUNCTION VOLTMETERS AND AMMETERS

Maker:—MESSRS CAMBRIDGE INSTRUMENT CO., LTD., 45 GROSVENOR PLACE, WESTMINSTER, S.W. 1.

Type and Number	Principle	Range (amps or volts)	Length of pointer mm.	Length of scale mm.	Accuracy % of top reading	Dimensions of case cms.	Remarks or special features	List Price £	s.	d.
41825	Thermo-junction	4 milliamps	96	120	1	17 × 16 × 15	Semi-suspended Unipivot	20	0	0
41337	Thermo-junction	8, 25 or 120 milliamps	96	120	1	22 × 19 × 11	Unipivot	11	0	0
41623	5 Thermo-junctions	10, 50, 100, 500, or 1000 milliamps	96	120	1	29 × 21·5 × 14	Multi-range type. Accuracy unaffected by frequencies up to 1 million periods per second	24	10	0
Radio frequency	Thermo-junction and transformer	250 or 500 amps	82	120	2	16·5 × 16·5 × 9·5 Transformer 40 × 36 × 19	Double pivoted instrument with Campbell and Dye transformer	53	0	0
2977	Thermo-junction	1·2, 6, 60, 120, 300 volts	96	120	1	21 × 29 × 13	Multi-range with safety switch and non-inductive series resistances. Sensitivity 100 ohms per volt	19	0	0
41631	Thermo-junction	10 milliamps	110	140	1	21 × 11 × 22	Duddell pattern	19	0	0
41633	Thermo-junction	100 milliamps	110	140	1	21 × 11 × 22	" "	19	0	0

JOURNAL OF SCIENTIFIC INSTRUMENTS

VOL. IV JUNE, 1927 No. 9

A UNIVERSAL X-RAY PHOTOGONIOMETER.

By J. D. BERNAL, B.A. Davy Faraday Laboratory

COMBINING: APPARATUS FOR SINGLE CRYSTAL ROTATION PHOTOGRAPHS—LAUE PHOTOGRAPHS—X-RAY SPECTROMETRY—POWDER PHOTOGRAPHS—PHOTOGRAPHS OF CRYSTAL AGGREGATES, METALS, MATERIALS, ETC.

[*MS. received* 19*th January*, 1927.]

PART I

INTRODUCTORY

THE applications of X-ray diffraction to problems in pure and applied science have reached such large dimensions that it becomes profitable at this stage to treat of instruments made for this specific purpose rather than to leave to each investigator the burden of creating special apparatus for his own needs. There is no reason why universal instruments should not be used, for all but very special problems, to give results as reliable and easily obtainable as those, say, of the spectroscope. The present papers are an attempt to describe first of all the general problem of the requirements and capabilities of apparatus for the different methods of X-ray crystallography, and secondly one particular universal instrument in detail with an account of its adjustment and operation.

X-RAY CRYSTALLOGRAPHY

The problems of X-ray crystallography divide themselves naturally into two parts:

(*a*) the determination of the inner atomic structure of the crystals of a pure substance;

(*b*) the determination of the mutual arrangement of small crystals in aggregates and mixtures.

To these may be added what is strictly not crystallography at all:

(*c*) the determination of the wave-lengths of X-rays from different sources.

Of these (*a*) is mainly important in theoretical and (*b*) in applied investigations, covering as it does the whole range of materials, metals, alloys, textiles, building materials and ceramics. (*c*) again is more of theoretical importance on account of the picture it gives of the atomic interior, although it will have a growing importance, second to if not greater than the spectroscope, in delicate qualitative analysis. These papers will concern themselves mainly with the analysis of single crystals, although the other aspects will be touched on in so far as the apparatus to be described has been designed to include them.

The Crystal Lattice and Planes

A crystal may be considered to be made up of a number of molecules or atoms, ultimately nuclei and electrons, arranged in sets which are repeated regularly in three dimensions. All

the sets are identical and similarly orientated. A point may be arbitrarily chosen in each set, each point occupying a similar position in its own set, and the assembly of these points defines *the lattice of the crystal*. If one point of the lattice is chosen as origin every point may be defined as a vector of the type

$$p\mathbf{a} + q\mathbf{b} + r\mathbf{c}$$

where $\mathbf{a}$, $\mathbf{b}$, $\mathbf{c}$ are three non-coplanar vectors of the lattice and p, q, r are integers. $\mathbf{a}$, $\mathbf{b}$, $\mathbf{c}$ are called the axes of the crystal and are completely defined when their lengths a, b, c, and the angles α, β, γ between them are given. (The choice of $\mathbf{a}$, $\mathbf{b}$, $\mathbf{c}$ is not unique, but they are usually chosen to exhibit the symmetry of the crystal and are then called the principal or crystallographic axes of the crystal.) The parallelopiped, three of whose sides are $\mathbf{a}$, $\mathbf{b}$, $\mathbf{c}$, is called the unit cell of the crystal. All the unit cells of the crystal are geometrically and physically indistinguishable.

The points of the lattice which obey the relation

$$hp + kq + lr = 1$$

where h, k, l are integers, are said to lie on the plane whose indices are h, k, l (the word plane is always used in crystallography in this restricted sense). The distance from the origin to this plane which is the same as the distance between the neighbouring parallel planes

$$hp + kq + lr = 2,$$

$$hp + kq + lr = 3, \text{ etc.,}$$

is called the spacing d of the plane (hkl). It is given by the formula

$$d = \frac{(\mathbf{abc})}{|\Sigma h[\mathbf{bc}]|},$$

or in scalar notation

$$d = \left\{\frac{1 - \Sigma\cos^2\alpha + 2\cos\alpha\cos\beta\cos\gamma}{\Sigma\frac{h^2}{a^2}\sin^2\alpha - 2\Sigma\frac{kl}{bc}(\cos\alpha - \cos\beta\cos\gamma)}\right\}^{\frac{1}{2}}.$$

The spacing of any plane (hkl) is of course independent of the choice of origin and represents, when h, k, l have no common factor, the distance through which the plane must be moved to arrive at a similar position in the crystal; or in the case where h, k, l may be put in the form nh', nk', nl', it represents $1/n$th of this distance.

The Diffraction of X-rays

A crystal acts towards a beam of X-rays as a three-dimensional diffraction grating and the incident beam of X-rays gives rise to a number of beams diffracted through different angles. The directions in which these beams emerge is most conveniently given by considering the incident beam to be reflected regularly by the various planes of the crystal, when and only when the wave length λ of the reflected beam, the spacing d of the plane and the glancing angle θ between the incident beam and the plane are related by Bragg's Law

$$\sin\theta = \lambda/2d.$$

In the sense in which spacing has been defined above the n in the original form of the law $\sin\theta = n\lambda/2d$ always reduces to 1. Although in the crystallographic sense a plane may as well be indicated by the indices (nh, nk, nl) as by (h, k, l), from the point of view of X-ray crystallography the former has a spacing $1/n$th the latter and gives a reflection at a different angle. This reflection may be considered as the nth order reflection of the plane (h, k, l),

but at any rate for the purposes of Rotation Photographs it is more natural to call it the reflection of the plane (*nh*, *nk*, *nl*).

The first task of crystal analysis is the determination of spacings. From a few such measurements the actual size and shape of the unit cell of the crystal can be found. It should be theoretically possible to find this from one measurement of spacing and the crystallographic axial ratios and angles. Unfortunately, owing to the arbitrary nature of these, the cell arrived at in this way may be one half or twice or some other rational fraction of the true cell, and such errors can only be overcome by measuring the spacings of a sufficient number of planes. From a knowledge of the cell size and the density of a crystal the number of atoms or molecules in the cell can be found. The further analysis of the crystal can only proceed by a knowledge of symmetry and intensity of reflections.

Intensity of Reflection

The intensity of the reflection from any plane depends essentially on the distribution of scattering power in the direction perpendicular to that plane; this is expressed by what is called the structure factor of the plane. To obtain the structure factor for a sufficient number of planes is the essential requirement for a complete analysis of a crystal. To obtain the structure factor however from intensity measurements requires corrections for extinction, absorption, polarization, temperature, etc., which are difficult to evaluate and often amount to as much as several hundred per cent. To proceed directly from the structure factors to the actual structure is impossible in the great majority of cases. The inverse method has in general to be followed. The positions of the atomic centres is first fixed as far as possible by considerations of symmetry, knowledge of atomic diameters and probable chemical configurations etc., and the models thus arrived at are tested and have their details filled in by a comparison of the structure factors predicted from them with those observed.

Symmetry

Of all the aids to the determination of structure the simplest to obtain and the most certain is that of symmetry. Crystals are divided into thirty-two symmetry classes determinable from their external form and properties and subdivided into two hundred and thirty space groups. Each space group is characterised by certain internal regularities which cause reflections from some planes to have zero intensities, *i.e.* to vanish, and the knowledge of the indices of the planes which do not reflect (in the usual terminology these are said to be halved, thirded, quartered, etc.) is usually sufficient to fix the space group by a simple reference to tables, such as those of Astbury and Yardley* or Wycoff. The space group itself may suffice to fix the positions of the atomic centres in the case of simple crystals; but in general it reduces the analysis of the crystal to a question of finding a limited number of parameters determining these positions by means of the intensity measurements. A knowledge of the number of molecules per cell and of the space group is sufficient to indicate the symmetry of the individual molecule, and the analysis of most organic and some inorganic crystals usually stops short at this stage, for lack of adequate intensity measurements or methods of interpretation for such complex crystals.

Experimental Data of X-ray Crystallography

The experimental data necessary for a complete crystal analysis may be summarised as follows:

(1) Measurement of spacings of planes of known indices leading to the determination of the size and shape of the unit cell.

* *Phil. Trans.* A, 224, p. 221.

(2) Measurement of crystal density from which with (1) the number of molecules per cell can be found.

(3) Determination of the symmetry class by the methods of ordinary crystallography.

(4) Determination of the indices of absent reflections leading with (3) to the determination of the space group; and this combined with (2) giving the molecular symmetry.

(5) Measurement of the intensities of reflections from planes of known indices, and of the correcting factors necessary to obtain the structure factors, from which, together with (4), the complete structure may be derived.

Experimental Methods

So far we have considered the necessary data for crystal analysis without thinking of how hey may be obtained experimentally. The broad divisions of experimental methods depend on the way the emergent beams of X-rays are observed and measured. Of the three methods of detecting X-rays, fluorescent screen, photographic plate and ionisation chamber, the first, owing to the low power of X-ray tubes and the inefficiency of screens is not, for the present, a practicable method, although it has possibilities. Of the other two, the photographic method has the advantage of being able to register a great number of reflections at once in a way that permits of accurate measurements of distances, whereas the ionisation method is greatly superior in its ability to measure reflection intensities directly. The methods of X-ray crystallography may also be considered from another standpoint, that of the position of the crystal itself. Referring to the expression of Bragg's Law

$$\sin\theta = \frac{\lambda}{2d}$$

we see that while d is a constant for any particular crystal plane, either λ or θ may be made to vary.

The Laue Method

In the first case the crystal is fixed, but the beam of X-rays is a white one, *i.e.* contains all values of λ within a certain range. Under these circumstances each crystal plane reflects only that portion of the beam that has a wave-length satisfying Bragg's Law for the particular value of its glancing value θ. This is the original method of Laue. The method of registering the emergent beam is here nearly always photographic. It can be seen that as the values of λ are not known, d cannot be found and the shape of the pattern produced depends only on the symmetry of the crystal and its position relative to the incident beam. The densities of the spots however do give some measure of the intensities of the reflections, but are subject to three large corrections: for the unequal distribution of intensity in the incident radiation and for the different absorption of different wave-lengths both in the silver bromide film and in the crystal itself, in addition to the ordinary corrections for extinction, etc., mentioned above. This, combined with the uncertainty resulting from the superposition of different orders of reflection makes its value for intensity measurements mainly qualitative. On the other hand the Laue photograph is often essential for determining the symmetry, and it is unsurpassed in the number of different reflections registered in one exposure.

Rotation Methods

If instead of fixing the crystal and varying λ we use a source of monochromatic X-rays and turn the crystal round some axis, usually perpendicular to the beam, then a certain number of planes will come in turn into the reflecting positions for the particular wave-length of the incident rays. The reflected rays may be received on a photographic plate or film as in the so-called Rotation Method or they may be followed by a movable ionization chamber which is the Bragg Ionization Spectrometer method. In both methods, as λ is

known and θ measured, d can be found. The Rotation Method can deal with more reflections and can give more accurate spacing measurements than the Ionization Spectrometer. Also, for reasons which will be explained, it is far more reliable than the present forms of Ionization Spectrometer in the determination of cell size and space group. On the other hand, though superior to the Laue method, it falls far behind the Ionization Spectrometer for measurements of intensity, requiring, as all photographic methods must, some form of Photometer. For intensity measurements the Ionization Spectrometer is the standard to which all other methods are referred. It has however the disadvantage of requiring fairly large crystals which limits its use to substances which crystallise well.

Powder Methods

Instead of varying θ by turning the crystal in the beam of X-rays we may use a crystal powder which is in effect a very large number of minute crystals orientated in all directions at random. Only those crystals reflect which offer planes satisfying Bragg's Law and the reflected beams spread out in cones whose angle is 2θ and depends only on d. The reflected beams may be received on a plate or in a movable ionization chamber. This is the powder method of Debye and Scherrer and of Hull. It has the great advantage of being applicable to almost all solid substances and especially to those that cannot be obtained even in minute ($>$ ·01 cm. in dimensions) single crystals. Moreover it is free from the troublesome secondary extinction corrections that apply in all other methods. On the other hand, there is nothing but the spacing to indicate what are the indices of any plane, and, except where the symmetry is high or where the cell size has been found by other methods, it is generally impossible to assign indices and the photograph is meaningless. Even when indices can be assigned the reflections after the first three or four overlap except in the simplest crystals, thus making intensity measurements useless.

Comparison of Methods

The range of utility and the accuracy of the various methods of X-ray crystal analysis can be conveniently summarised as in the table on p. 278.

Combination of Methods

It will be seen that no single method gives satisfactory results in all classes of measurement, so that while it is possible and sometimes inevitable that only one method should be used, the full value of an analysis cannot be realized without employing all methods to amplify and check each others results. It may be said roughly that the Laue method and the rotation method are necessary for the preliminary work of determining the cell and the space group while the painstaking and accurate intensity measurements of the Ionization Spectrometer are necessary to establish the details of the structure; the Powder method being used as an auxiliary capacity or in those cases, which are much rarer than is supposed, where single crystals cannot be procured. Luckily the use of five different methods of analysis does not require as many forms of apparatus. All the photographic and all the ionization methods can be combined into two instruments: the X-ray Photogoniometer and the Ionization Spectrometer. The purpose of these papers is to give the principles of construction of the former instrument and an account of its use for Rotation Photographs in particular. The technique of Laue Photography is dealt with in Wyckoff's "The Structure of Crystals," Ewald's "Krystalle und Röntgenstrahle" with a convenient summary of papers by Schiebold, *Z. p. P.* **28**, p. 355, 1924, while the classical "X-rays and Crystal Structure" gives the best account of the Ionisation Spectrometer. For technical applications and descriptions of apparatus Mark's "Die Verwendung der Röntgenstrahle in Chemie und Technik" is invaluable.

	Laue Photograph	Rotation Photograph	Ionization Spectrometer	Powder Photograph	Ionization Spectrometer (powder)
Applicability to crystals of different sizes	Medium 0·1–·01 cm.	Medium 0·1–·01 cm.	Large > 0·1 cm. with developed or ground faces	Small < ·01 cm.	Small < ·01 cm.
Applicability to crystals of different symmetry	All	All	All, but troublesome with mono- and triclinic crystals	Only cubic tetragonal, trigonal and hexagonal crystals	Only cubic tetragonal, trigonal and hexagonal crystals
Number of reflections observed	Very many, usually hundreds	Many, up to two hundred	Any number, but troublesome and slow, usually about forty	Usually not more than forty, very crowded	Very few
Determination of indices of reflecting planes	Simple and certain	Troublesome, but certain with care	Certain, but troublesome, especially for general planes	Almost impossible, except for planes of low indices	Almost impossible, except for planes of low indices
Measurement of spacing	Impossible	Highest ob-obtainable accuracy	Accurate	Fairly accurate but for overlapping	Fairly accurate but for overlapping
Measurement of cell size	Only indirectly from other methods	Simple and certain	Liable to errors in complex crystals	Fairly good, where indices can be found	Fairly good
Determination of symmetry class	Best X-ray method	Poor indirect method	Possible from intensity measurements	Impossible	Impossible
Determination of space-group	Only indirectly, liable to error	Best method	Certain only if enough planes be observed	Possible if enough indices can be determined	Possible
Accuracy of intensity measurements	Very poor, too many corrections necessary	Better than Laue method	Standard method, but extinction corrections necessary	Best photographic method	Most accurate, less corrections, but limited application

The X-ray Photogoniometer

The Photogoniometer consists essentially of three parts:

(1) A system of apertures for limiting the breadth and angular divergence of the incident beam of X-rays.

(2) A goniometer head for holding the crystal in the beam of X-rays, for adjusting it in different angular positions and for allowing it to be turned uniformly about an axis perpendicular to the beam through a complete rotation or only through limited angles. This involves some form of steady running electric or clockwork motor.

(3) A photographic plate placed perpendicular to the incident beam behind the crystal which registers all the reflected beams within a fairly small solid angle. When a larger solid angle is required, a film is employed surrounding the crystal supported in a cylindrical camera whose axis is the axis of rotation of the crystal.

Besides these essential features others may be added for special purposes. The most important are a flat crystal plate holder, taking the place of the goniometer head, which converts the instrument into an X-ray spectrometer; and a collimator and telescope to assist in setting the crystal and which converts the instrument into an optical goniometer. It is sometimes useful but by no means necessary to be able to have the incident beam not perpendicular to the axis or to have the plate not perpendicular to the incident beam.

Theory of the Rotation Method

When such an instrument is used for the rotation method a beam of X-rays from a tube with a copper (iron or molybdenum, etc.) anticathode to produce a monochromatic radiation

(really K_{α_1}, K_{α_2} and K_β) falls on the crystal which is kept rotating continuously. Each time a plane comes into the reflecting position (this happens in general four times in a revolution) it makes a trace on a certain spot of the photographic plate and in the course of a sufficient number of revolutions leaves a visible spot on the plate. In general each plane gives rise to four spots which, in the usual case of the beam being perpendicular to the axis, are symmetrically distributed about lines on the plate parallel to and perpendicular to the axis. The photographic density of any spot is simply proportional to the total time of exposure and by lengthening this every reflection however faint will be registered. There is however a limit below which a spot will not appear against a background fogged by general scattering and white radiation but this difficulty can be overcome by the oscillation method (see p. 283). In the pattern of spots that makes up a rotation photograph (see Pl. I) each spot corresponds to a reflection from a plane of the crystal, and it is the first task of analysis to determine the indices of the planes corresponding to every spot (usually referred to as the indices of the spot). The determination of the unit cell is found to be one step in this process.

The Reciprocal Lattice

The interpretation of rotation photographs is enormously simplified by the use of the mathematical device of the Reciprocal Lattice, first introduced by Ewald*. Here only the mere outline of the theory of the reciprocal lattice is attempted; for a fuller treatment the reader is referred to the original paper, and for its particular application to the rotation method to papers by Schiebold†, Maugin‡ and the author§. Starting with a crystal lattice defined by the three axes **a**, **b**, **c**, another lattice may be formed each point of which corresponds to a plane in the other (planes being understood in the restricted sense previously referred to) so that the point corresponding to any plane of spacing d lies on the normal from the origin to the plane at a distance ρ from the origin, given by

$$\rho d = \kappa^2,$$

κ being an arbitrary constant. The lattice made up of such points is called the reciprocal lattice of the crystal. The axes of the reciprocal lattice are the vectors $\mathbf{a}^*$, $\mathbf{b}^*$, $\mathbf{c}^*$ reciprocal to **a**, **b**, **c**, that is, where:

$$\begin{array}{llll} \mathbf{a}^* = \sin\alpha/Na & \text{and is perpendicular to the plane} & & \mathbf{b}\ \mathbf{c}, \\ \mathbf{b}^* = \sin\beta/Nb & ,, & ,, & \mathbf{c}\ \mathbf{a}, \\ \mathbf{c}^* = \sin\gamma/Nc & ,, & ,, & \mathbf{a}\ \mathbf{b}, \end{array}$$

where $N = \{1 - \Sigma \cos^2\alpha + 2\cos\alpha\cos\beta\cos\gamma\}^{\frac{1}{2}}$.

In the important particular case where **a**, **b**, **c** are mutually at right angles $\mathbf{a}^*$, $\mathbf{b}^*$, $\mathbf{c}^*$ are parallel respectively to **a**, **b**, **c** and $\mathbf{a}^* = \kappa^2/a$ etc. The point $h\mathbf{a} + k\mathbf{b} + l\mathbf{c}$ in the reciprocal lattice corresponds to the plane (hkl) of the crystal. If κ^2 is chosen equal to λ, the wavelength of the incident radiation, Bragg's Law becomes for the reciprocal lattice:

$$\rho = 2\sin\theta.$$

The advantage of using the reciprocal lattice for rotation photographs is that the reflection from any plane corresponds both to a spot on the photographic plate and to a point of the reciprocal lattice and that the distribution of spots on the plate is closely related to the distribution of points in the reciprocal lattice.

* *Z. f. Kryst.* v, **56** (1921) 129.
† *Z. f. Physik*, v, **28** (1924) 355.
‡ *Bulletin de la Société Française de Minéralogie*, t. XLVIII (1926).
§ *Proc. Roy. Soc.* A, **5** (1926) 113.

Rotation Diagram Coordinates

For rotation photographs the most convenient coordinate system to which to refer the points of the reciprocal lattice are the cylindrical coordinates ξ, ω, ζ; ξ being the distance of any point from the axis, ζ its height above the equatorial plane through the origin, and ω its azimuthal angle with respect to some arbitrary fixed line. Of these only ξ and ζ can be found directly from the photograph as there is nothing to show exactly at what angle any

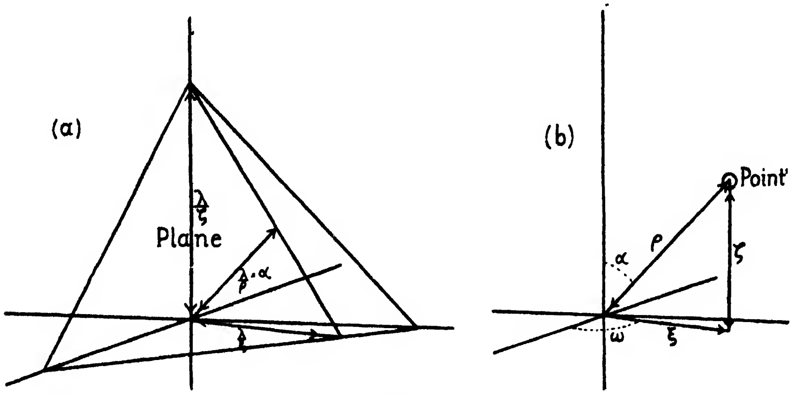


Fig. 1

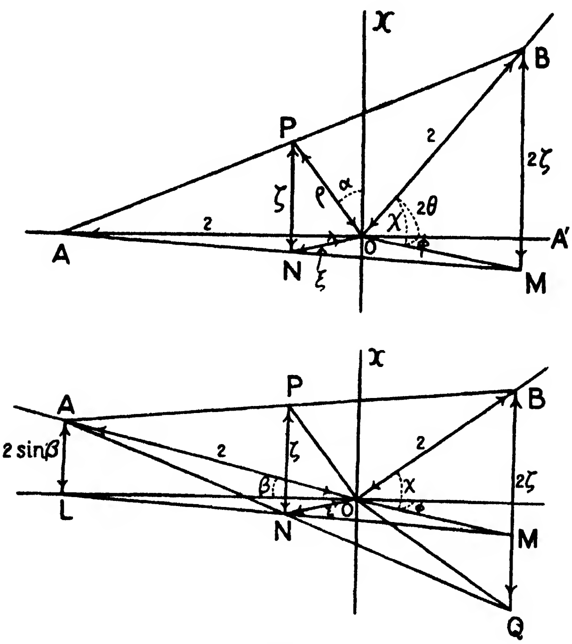


Fig. 2

plane reflects. We have of course $\rho^2 = \xi^2 + \zeta^2$. In the crystal lattice ξ corresponds to the reciprocal of the distance of the trace of the corresponding plane in the equatorial plane from the origin, and ζ to the reciprocal of the intercept of the corresponding plane on the axis (see Fig. 1). A diagram on which all the ξ and ζ values of the reciprocal lattice are plotted is called a rotation diagram. It may be considered to be produced by rotating the reciprocal lattice about the axis and marking the traces of each point on any meridian plane.

Transformations

The coordinates of points on the rotation diagram are related to the angular coordinates χ and ϕ of the reflected beams by the equations

$$\xi = \{1 - 2\cos\chi\cos\phi + \cos^2\chi\}^{\frac{1}{2}},$$
$$\zeta = \sin\chi,$$

where χ is the angle measured from the equatorial plane and ϕ that measured from the principal plane, *i.e.* the meridian plane passing through the incident beam (see Fig. 2). The above equations only hold when the incident beam is perpendicular to the axis. In the more general case, where it is inclined at an angle $\pi/2 - \beta$, we have

$$\xi = \{\cos^2\beta - 2\cos\beta\cos\chi\cos\phi + \cos^2\chi\}^{\frac{1}{2}},$$
$$\zeta = \sin\beta + \sin\chi.$$

In order to be able to interpret the rotation photographs, ξ and ζ must be given in terms of quantities directly measurable. The most suitable are the Cartesian and polar coordinates of the spots on the plate or on the unrolled cylindrical film. For the former we have, for a plate distance D from the crystal,

$$\xi = \left\{2 - \frac{2}{\left\{1 + \frac{r^2}{D^2}\right\}^{\frac{1}{2}}} - \frac{\frac{y^2}{D^2}}{1 + \frac{r^2}{D^2}}\right\}^{\frac{1}{2}},$$

$$\zeta = \frac{\frac{y}{D}}{\left\{1 + \frac{r^2}{D^2}\right\}^{\frac{1}{2}}}.$$

For a cylindrical film of radius R

$$\xi = \left\{1 - \frac{2\cos\frac{x}{R}}{\left\{1 + \frac{y^2}{R^2}\right\}^{\frac{1}{2}}} + \frac{1}{1 + \frac{y^2}{R^2}}\right\}^{\frac{1}{2}},$$

$$\zeta = \frac{\frac{y}{R}}{\left\{1 + \frac{y^2}{R^2}\right\}^{\frac{1}{2}}}.$$

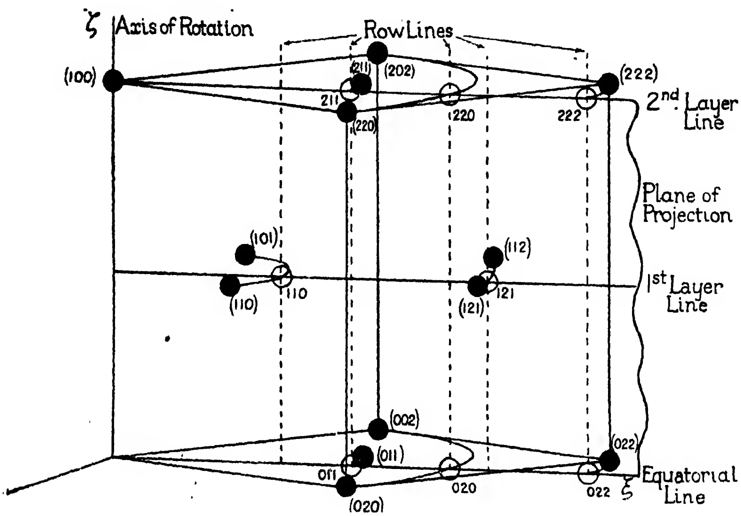
Interpretive Charts

From these equations or their equivalents ξ and ζ may be calculated and tables for this purpose are given in the author's paper*, but the work is rather laborious because of the number of spots involved, and by the use of two charts prepared by the author the necessity of calculation is done away with, except where great accuracy is required. The photograph is simply projected on to the chart by means of an enlarging lantern until the image corresponds to a plate distance of 10 cms. for the plane chart or for a camera radius of 5 cms. for the cylindrical chart, and ξ and ζ can be read off directly in either case. This method achieves a great saving of time and trouble without serious loss of accuracy. From the ξ and ζ values thus obtained a rotation diagram is constructed and compared with the theoretical rotation diagram derived from the reciprocal lattice. In this way the indices of the reflecting planes can be immediately determined. The detail of the method is explained in the author's paper, but the general principles are as follows.

* *Proc. Roy. Soc.* A, v (1926) 113.

Measurement of Cell Size

If a crystal is rotated about any zone axis, *i.e.* along a line joining any two points of the lattice, this is equivalent to rotating the reciprocal lattice about an axis perpendicular to a corresponding plane of points (see Fig. 3). It is easy to see that the ζ of the reflected beams



● (222) Point of reciprocal lattice ○ (222) Point of rotation diagram

Fig. 3. Formation of Rotation Diagram from a face-centred cubic reciprocal lattice, corresponding to a body-centred crystal

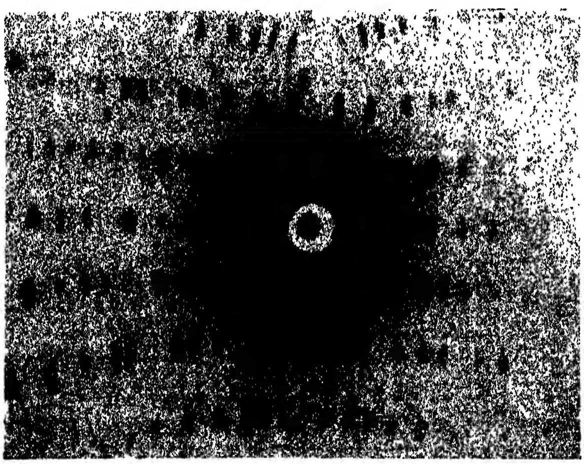


Fig. 4. Typical zone axis rotation photograph. The original was taken by rotating a monoclinic needle-shaped crystal about the b axis at 4 cms. from the plane photographic plate in a pencil of X-rays from a copper anticathode

will have values which will all be multiples of the perpendicular distance between planes parallel to the equatorial plane. Each set of reflections corresponding to a layer of points in the reciprocal net will lie on a line on the plate. These lines are called "layer lines" (see Fig. 4). On the plane plate they are hyperbolas; on the cylindrical film, straight lines.

The constant ζ differences between adjacent layer lines give immediately the length of the primitive translation, *i.e.* the distance τ between lattice points in the direction of the axis by the simple relation

$$\tau = \frac{\lambda}{\zeta}.$$

If we take the three principal axes a, b, c of the crystal in turn as axes of rotation, their length and consequently the exact size of the unit cell may be found from this relation. Some difficulties exist in monoclinic and triclinic crystals owing to the arbitrary way in which crystallographers are obliged to assign axes. But these can easily be overcome. From these measurements the size and shape of the cell of the reciprocal lattice can be found even more directly, for in orthogonal crystals a^*, b^*, c^* are of course given by the three ζ intervals. The ξ and ζ values for the plane (hkl) of any orthogonal crystal rotated about its axis are

$$\xi = \{\kappa^2 b^{*2} + l^2 c^{*2}\}^{\frac{1}{2}},$$
$$\zeta = ha^*.$$

Here the reflections of all planes which have the same first index h, lie on the same layer line, while the reflections of planes with the same kl indices lie on the lines of equal ξ the so-called "row lines." These values may be calculated and compared plane by plane with the observed values of ξ and ζ or graphical methods may be used throughout and in either way the indices of the reflecting planes may be determined. In monoclinic and triclinic crystals the procedure is more complicated as no row lines appear on photographs taken about crystallographic axes. And here the method of taking photographs not about axes but about normals to crystal faces can be used to advantage. In this case row lines appear and not layer lines.

Resolution of Spots

If the spots on the photograph could be reduced to geometrical points the methods outlined above would be sufficient to determine the indices of all spots on a rotation photograph but unfortunately the spots are of finite size and often overlap except in the more symmetrical classes, *i.e.* cubic, tetragonal, trigonal and hexagonal. To escape the uncertainty introduced in this manner, which is analogous in two dimensions to the overlapping of Debye rings in powder photographs, it is possible by various methods, such as reducing spot size, use of more accurate adjustment, methods of mis-setting crystals to spread spots, etc., to reduce the overlapping to a minumum. Nevertheless with complex organic crystals with large cells all these methods fail because the spots are so numerous and close together, and it is necessary to make use of the angular position of the crystal on reflection in order to identify the spots. This is equivalent to introducing the third co-ordinate ω of a reciprocal lattice.

The Oscillation Method

If instead of rotating the crystal through a complete revolution the rotation is limited to a uniform back and forth movement through 5 or 10 degrees, only a limited number of planes will reflect. The indices of planes which reflect for any particular range of oscillation can be calculated, or much more easily found by a very simple geometrical construction described in the author's paper*. In such a limited range the chance of overlapping almost disappears and by going over the crystal section by section in this manner every spot can be identified. The usefulness of the oscillation method is much wider than its ability to resolve confused spot patterns. By its use the relative length of exposure of each photograph is much shortened so that it brings up spots which are too faint or hidden in the fogged background to appear in ordinary rotation photographs, and it is also extremely useful for setting crystals without developed faces.

* *Proc. Roy. Soc.* A, v (1926) 150.

Summary

The operations necessary for the determination of cell size and indices by the method of rotation photograph may be summarised as follows:

(1) Three photographs are taken with complete rotation about each of the three principal axes of the crystal in turn.

(2) The ζ values of the layer lines in each photograph are measured and the axial lengths a, b, c of the crystal and a^*, b^*, c^* of the reciprocal lattice are determined.

(3) The ζ and ξ values of each spot on the photograph are calculated or found directly from a chart. They are compared with the theoretical values calculated for planes of known indices of the reciprocal lattice. Alternatively, the comparison may be made graphically between the observed rotation diagram and that derived from the reciprocal lattice. In this way the indices of each spot are determined, but if all the spots are not separate it is necessary to proceed to (4).

(4) A series of photographs are taken, each one being a rotation or oscillation about a principal axis of the crystal through a limited angle of 15, 10 or 5 degrees according to the complexity of the crystal. The indices and ξ, ζ coordinates of the planes which should reflect in each of these oscillations are found graphically or by calculation and compared with those obtained from the photograph. In this way the indices both of the planes appearing on the photographs and of those which do not appear are found.

My thanks are due to the Royal Society for the loan of the blocks of Figs. 1–3, and to Dr W. H. George for the photograph reproduced in Fig. 4.

GEODETIC LEVEL RODS, THEIR CONSTRUCTION, AND METHOD OF GRADUATING. By DOUGLAS L. PARKHURST.

U.S. Coast Geodetic Survey, Washington, D.C.

[*MS. received, 4th January*, 1927.]

ABSTRACT. The construction and graduations of the rod used in geodetic levelling of the most precise character, the material used and treatment to overcome variations in temperature and humidity are described. The graduating of these rods has been one of the most difficult processes; and a machine is described which has been built for this purpose and which performs the most exacting part of the work mechanically.

Introduction

In geodetic surveying, where absolute differences in elevation must be determined with the utmost practicable accuracy, the ordinary levelling apparatus is replaced by a more accurate and sensitive instrument and a rod of special design. The rod, as it is now constructed by the U.S. Coast and Geodetic Survey, is the result of years of experience and experimentation with various materials and methods of treatment, and with various methods of graduating.

For instance, prior to 1916, a wooden rod was used with the graduations painted upon the face. In order to counteract climatic changes the material was boiled in paraffin, but it was found that this made the rod exceedingly heavy and reduced the resilience by a marked amount, but it was also found that while frequently a rod's length would check when determined in the spring and fall at the beginning and the end of the season, yet during the season there was a definite change in the length which introduced an error in

the readings, yet which would gradually correct itself so that it remained undetected at the post-season checking. As a result the present type of rod was developed.

Description

The rod, shown in Fig. 1, consists of a graduated metal strip rigidly attached to a steel footpiece, the latter being fastened to a wooden back which supports the strip.

As it is essential that there shall be practically no variation in the length of the rod due to changes in temperature, the metal strip on which the graduations are placed is of a material having an extremely low temperature coefficient, such as invar. The wooden portion of the rod merely acts as a support, and, although the strip is restrained from side-wise motion by virtue of being held in a slot in the wood, it is free to move longitudinally.

The wooden portion of the rod must be straight, stiff and light, and the wood must be of a character which will not readily take a permanent set if laid horizontally without support throughout.

Some of the earlier rods used by the U.S. Coast and Geodetic Survey had a brass foot-piece, with an iron plug driven into the lower end, and with a strip of invar attached to this footpiece upon which the graduations were painted. It was found that the blows on the footpiece occurring when the rod was placed in position gradually upset the softer brass, loosening the steel plug and introducing an error in the length of the rod. The all-steel footpiece obviates this trouble.

The rod used to-day is made up of a strip of invar having a temperature coefficient not in excess of ·000002 per degree Centigrade. This strip is about 3·3 metres in length and a temperature change of 50° Fahrenheit, a change which might readily occur during a working day, will cause a difference of only $\frac{8}{1000}$ of an inch in the entire length, an amount which under ordinary conditions would be negligible. For the most precise work, however, this is corrected for by computation, thermometer readings of the temperature of the strip being taken while the rod is in use.

The invar strip "A" referred to above is fastened by a brass machine screw and two dowel pins to the cast steel footpiece "B." This strip is 26 millimetres wide and 1 millimetre thick. The lower surface of the footpiece is case hardened and is ground flat and normal to the surface against which the wooden back "C" is fastened, and which is also ground flat. The wooden back is made of a single piece of well-seasoned, straight grained white pine free from knots, wind shakes and other defects. After roughing out these pieces are given a coat of raw linseed oil and suspended from one end for a considerable length of time and only those which remain straight are used. The back is securely fastened to the footpiece by four brass bolts through the face and two brass wood screws in the end. A small groove slightly wider than the invar strip is routed out through the entire length of the face and deep enough so that the strip is free to move underneath a number of brass washers recessed to fit flush with the face. A handle, for convenience in carrying, is attached to the back near the centre of gravity.

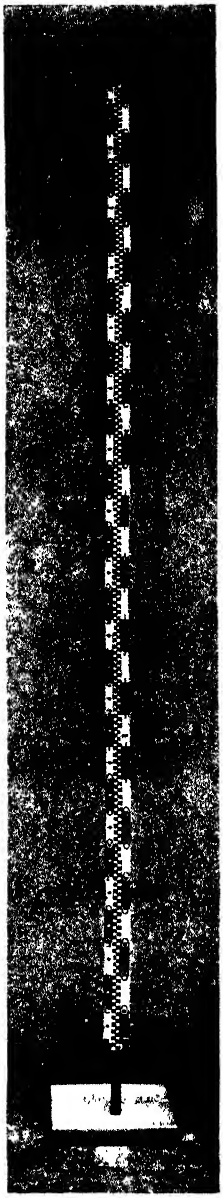


Fig. 1

To prevent swelling, the wooden part of the rod is treated by applying a heavy coat of raw linseed oil, three coats of orange shellac, and two or three coats of high grade white lead paint. This furnishes an excellent protection against moisture and in no way affects the resilience.

The thermometer used for determining the temperature of the strip is accurate to 0·5° Centigrade and is of special construction, having an unusually fine capillary and having the bulb bent backward at 45°. This is located in a recess, the bulb resting against the rear surface of the invar. In order to eliminate any error, which might occur due to sagging of the strip when the rod is held erect, it is placed under tension by a stiff spring set in a recess in the back and pressing against a small brass angle plate attached to the top of the strip.

The graduations are in the form of alternative squares of black and white painted on the invar. As metric units are used the squares are one centimetre in width. To facilitate reading, the wooden face of the rod is laid off in decimetre spaces, coloured alternately black and white, those on one side of the rod being staggered with respect to the other. Each decimetre line bears the proper numerals, reading from the base of the rod as zero. The black and white diamonds, placed half-way between decimetre lines, are to assist the observer in reading.

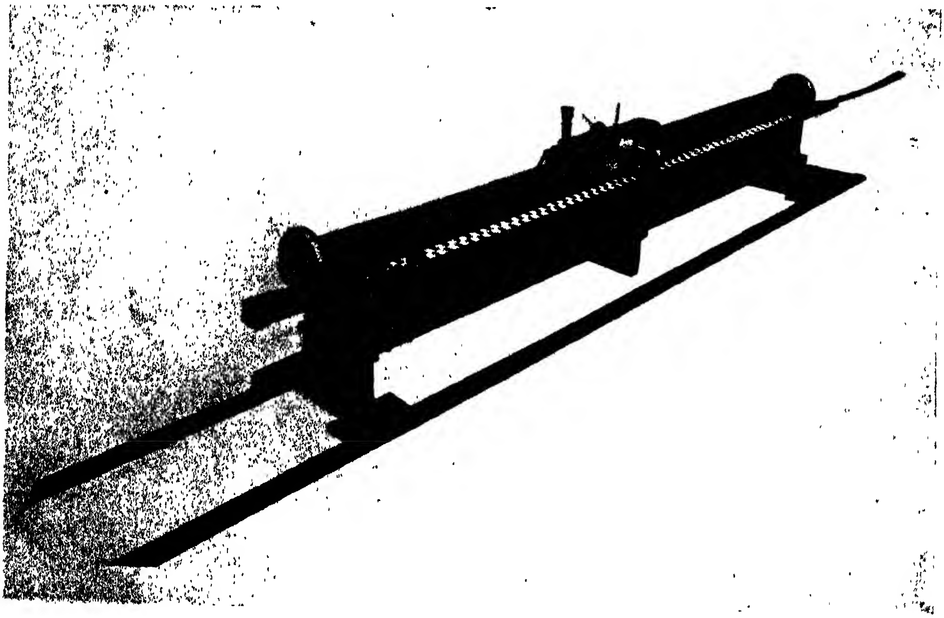


Fig. 2

To furnish a check on the observations, the rear surface of the wood is graduated roughly in English dimensions. Both sides of the rod are read and recorded at each station to locate an occasional gross error which might remain undetected if a compensating error of similar magnitude were made on the opposite running of the section. The painting of the squares with the desired accuracy on the invar strip has required the construction of a special graduating machine, which is shown in Figs. 2 and 3.

Formerly, the graduations were applied by placing the strip, which had previously been given several coats of white enamel, beside a master scale which had been carefully divided into centimetre spaces and then transferring the lines to the strip by hand, using a steel square and scriber. The black squares were then filled in by hand, a most tedious process. It was impossible to obtain uniformity of width, as the scriber cut a shallow groove of finite width, allowing the black paint to flow slightly beyond the actual centre line, thus causing a general tendency for the black squares to be wider than the white. Variation in the depth of the grooves due to unevenness of pressure on the scriber, or in the guiding, caused irregularities in the line of demarcation.

In the new machine the comparison method is used, thereby avoiding the necessity for cutting a long and accurate lead screw. The comparator bar is of invar of the same physical characteristics as the strip, consequently there is no necessity for working at a constant or definite temperature. This bar is 1 metre long and is accurately ruled in 1 centimetre spaces. It is held in a groove at the rear of the machine and the settings are made with a microscope which is mounted on the carriage and has a pair of fine tungsten wires in the focal plane. A small electric bulb, properly shaded, is placed beside the microscope and shines down upon the comparator bar, causing the ruled lines to stand out brilliantly, while the tungsten wires show as intensely black against this brilliant background. The setting of the carriage is surprisingly easy.

The cross slide carries a vertical element on which is mounted a cup-shaped turreting mask, having four rectangular slots one centimetre in width cut in the rim. The turret is lowered and pressed against the work by a small eccentric and then the open space is

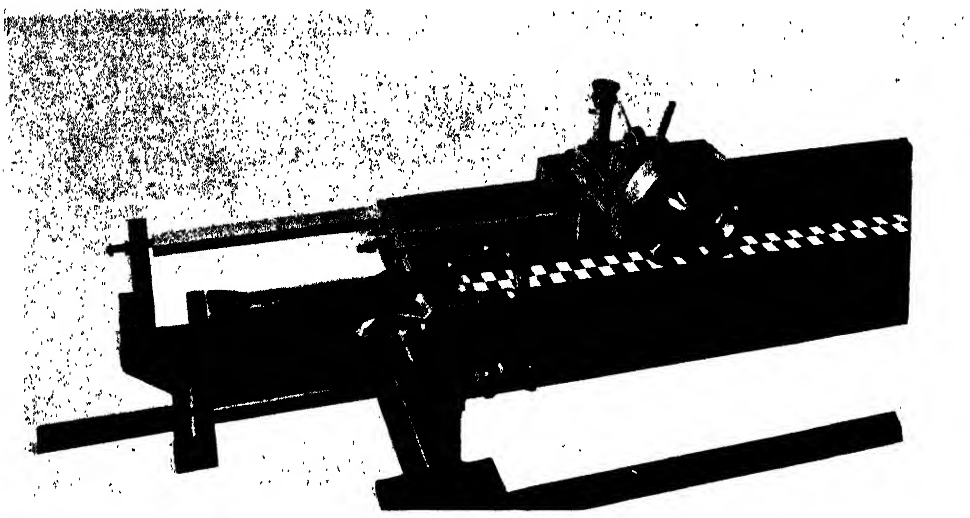


Fig. 3

sprayed with a quick drying black paint by means of a small air brush. As the mask is raised vertically no difficulty is experienced with smearing and it is not necessary to wait until the paint dries. As soon as a square has been completed the mask is raised, the carriage traversed to the next space, and the process repeated.

Only one side of the strip can be painted at a time and after completion the strip must be reversed in the machine and the other side graduated.

Resulting graduations, both black and white, are all of the same width. The lines of demarcation are straight and sharp and the sharpness is enhanced by the thinness of the film of black, which does not provide a raised and shining surface to cause annoying reflections, as is the case in hand application.

In order to make the one metre line exactly one metre from the lower surface of the footpiece and to make all rods exactly alike so that pairing is unnecessary, a stop has been placed on the machine which is so adjusted that when the strip with its footpiece is clamped in the machine and the comparator bar moved down against this stop the one metre line on the bar is exactly one metre from the lower end of the rod.

Tests of this machine have shown that sharper and more accurate graduations can be applied in approximately half the time required by the hand method.

PROGRESS IN THE DESIGN AND CONSTRUCTION OF ELECTRICAL INSTRUMENTS. By DR C. V. DRYSDALE.

(*Continued from p. 251*)

Resistance Standards and Standardising Bridges. From the British Association meeting of 1862 up to the War great interest and progress was shown in the construction and comparison of resistance standards, but the fascinating problems of radio and valve research seem to have quite pushed such matters into the shade and there seems to be a prevailing impression that there is no need for further improvement. Certainly the great advance which was made by Dr Weston's discovery of Manganin in 1888, and its application to well cooled resistance standards by Dr Lindeck of the Reichsanstalt, has put matters on a much better basis than in the old days of platinoid or platinum silver coils embedded in paraffin wax; but we have most certainly not yet arrived at standards of reliable constancy, in spite of the strong claims of permanence which have been made by eminent authorities. As a general rule manganin coils of resistance above an ohm are fairly constant, although disconcerting unexplained variations may sometimes occur, but the strip resistances of low value which are of such great importance for accurate current measurement seem prone to rise more or less steadily for years, and I have never personally come across one either of British or German construction which did not increase in resistance by about 0·1 per cent. per year and be anything from 0·25 to 0·5 per cent. high after a few years' careful use. Whether it is due to separation of the materials in rolling the strip or the effect of joints seems still doubtful, but more investigation seems needed on this point, and possibly the X-ray spectroscope which has cast light on many other puzzling phenomena may help us in this direction also.

The essential and desirable features of a resistance standard may be enumerated as follows: Permanence, low temperature variation, low thermo E.M.F. to copper, large current capacity and ample cooling, provision for accurate determination of temperature, high insulation, satisfactory terminals, and negligible inductance or capacity for high frequency working. The various forms of standards designed at the Reichsanstalt go far towards satisfying the bulk of these requirements, but the low resistances are of straight strips and make no pretence to be non-inductive. The writer has designed various forms of low resistance in which the inductance is greatly reduced, by doubling the strips or by a double concentric cylinder system, while an ideal non-inductive resistance is afforded by the concentric system of Moore, in which the resistance is in the form of a tube with an inner return electrode, so that the whole of the magnetic field is confined to the internal space and there is no inductive effect whatever on potential leads connected to the ends of the resistance tube. This principle is of very great value for high frequency resistances, and its only objection is that it is somewhat clumsy for heavy current standards.

For standards of $0{\cdot}1\omega$ and upwards there is much to be said for an open coil non-inductively wound in a cage round corrugated glass or porcelain pillars, and such forms are now obtainable. One source of variation in the Reichsanstalt form of high resistance standards shellaced on to metal bobbins was found by the Bureau of Standards to be absorption of moisture, causing expansion of the varnish through moisture, which produced varying strains in the wire.

Great advances have been made in standardising bridges since the early form of Carey-Foster bridge, which did such good service in the days of the B.A. standards. This form of bridge, which is practically perfect for two terminal resistances, is inapplicable for the coils with separate current and potential terminals which are now universally employed for

resistances of 1ω downwards, and the Kelvin double bridge principle with two sets of ratio coils has to be employed. In 1895 Dr Lindeck produced such a double bridge for the accurate comparison of coils of nearly equal resistance, by the employment of ratio coils with interpolation resistances, by which balance could be varied by 0·1 per cent. on either side and the exact difference between the coils deduced from the corresponding deflections or by shunting, to about one part in a million; and a few years later the writer modified the Carey-Foster bridge to include inner ratio coils on the Kelvin bridge principle. This latter form has since been improved by the use of a double slide wire applied to ratio coils with interpolation resistances—so that it reads the differences between coils directly in parts per million and is very convenient for standards of any value from the lowest to the highest values, and also has built-up ratio coils enabling coils of nearly all values required to be determined from a single standard. Dr F. E. Smith has also produced a standardising bridge working either by deflections or by shunting, by which he has effected comparisons between coils to 1 or 2 parts in ten-million. At present, therefore, the accuracy of comparison of resistance standards is far in advance of their permanence, and it is greatly to be hoped that someone will take up the matter afresh and bring up the standard resistance to a really reliable state.

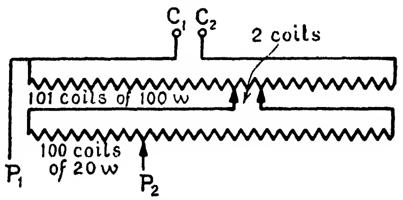


Fig. 19. Kelvin and Varley Slides

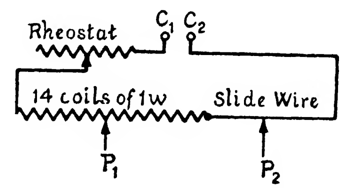


Fig. 20. Crompton Potentiometer

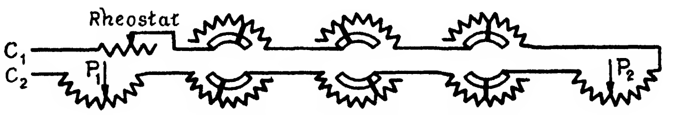


Fig. 21. Feussner Potentiometer

Potentiometers. Of all instruments for accurate measurements the most generally useful is the potentiometer which was first put into practical form by Crompton in 1885, although the Kelvin and Varley slides which form an excellent dial potentiometer had existed for some time. British and Continental practice as regards these instruments have followed different lines. The Crompton potentiometer contained a dial of fourteen resistance coils each of 1ω and a bridge wire, while the Germans have adhered to the lines originally laid down by Feussner of the Berlin Reichsanstalt in 1903 by making their potentiometers entirely of dials. Figs. 19, 20, and 21, show the essential elements of the Kelvin and Varley slides, the Crompton, and the Feussner potentiometer respectively, and a comparison of them is of some interest. In the first, one dial is provided with one extra coil, and two sliding contacts move together so as always to bridge two coils. Between these two contacts the second dial is connected, the total resistance of which is equal to two coils of the first dial, reducing the parallel resistance and the P.D. between the contacts to that of a single coil. In the original Kelvin and Varley slides the first dial had 101 coils of 1000 ohms each and the second 100 of 20 ohms, but for a decade system this principle may be extended to any number of dials, the resistance of a coil in any dial being one-fifth of that in the previous dial. The objection to this arrangement apart from the somewhat difficult construction of the double contact is that either the potentiometer must be of very high resistance and consequently insensitive, or contact errors are liable to come in on the lower dials, owing to

their very low resistance. If the first dial has a resistance of 10ω per coil, those of the second will be 2ω, of the third $\cdot 4\omega$, of the fourth $\cdot 08\omega$, and of a fifth $\cdot 016\omega$. The Feussner type of potentiometer, Fig. 21, has the advantage as regards simplicity of contacts, but requires all the coils to be duplicated to keep the resistance in the current circuit constant as the P.D. is varied, and it has the same objection as regards resistance as the Kelvin and Varley slides, as the resistance of the coils of each successive dial is only one-tenth of those of the preceding one.

The Crompton arrangement is by far the most simple and convenient in working and can be made of very low resistance as there are no contacts whatever in the current circuit. Its disadvantage is that it is not capable of high accuracy at low voltages, as the slide wire has a P.D. of 0·1 volt and unless the wire is extraordinarily uniform it is hardly possible to subdivide this to less than 1 per cent. or to 1 millivolt. In modern low resistance for current measurement 0·1 volt is generally the maximum P.D. allowed in order to avoid very large and costly construction and power loss, so that an accuracy of much within 1 per cent. in current measurements with this type of potentiometer can hardly be expected, unless a "transposition" device, i.e. shunting the potentiometer with a ninth and adding a resistance of 0·9 of its resistance to reduce the current and P.D. across its coils to one-tenth is employed. On the whole, therefore, the writer is inclined to think that the best compromise is a potentiometer made up with two dials either on the Kelvin and Varley or the Feussner principle,

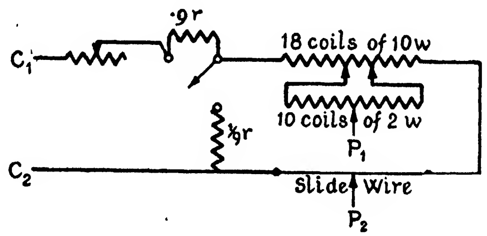


Fig. 22. Tinsley 2 Dial and Slide Wire Potentiometer with Transposition Circuit

and a slide wire; and Messrs Tinsley have for many years constructed a "Universal Potentiometer" on the former principle with the addition of the transposition device permitting it to read down to 10^{-5} volt (Fig. 22).

Deflection Potentiometer. A type of potentiometer which is in fairly considerable use in the U.S.A., but which does not seem to have received much attention in this country, is the deflection potentiometer of Mr E. Brooks of the Bureau of Standards. In this type of potentiometer a single series of resistance coils only is required to balance the P.D. to the nearest ·01 volt, and the residuals are indicated on a pointer galvanometer. As successive steps in the resistance dials do not give equal deflections, compensating resistances are added to secure this, and the instrument then becomes very convenient and rapid in operation, as it is only necessary to turn the dial until the pointer is on the scale and then to read off the P.D. from the dial and deflection directly. Of course such an instrument works on the assumption that the external resistance in the P.D. supply is negligible so that it is only suitable for power circuits, but it is extremely convenient for glow lamp testing and other cases where accurate measurement of a supply voltage is necessary.

Potentiometers for small P.D.'s. For the measurement of very low P.D.'s such as those from thermo-couples, however, potentiometers of any of the above types are not reliable, owing to the thermo and other E.M.F.'s which may occur at the sliding contacts of the derived circuit. A potentiometer for such low P.D.'s should have a very low resistance in order to be able to use a low resistance galvanometer, and should have its potential contacts fixed so as to avoid any possibility of contact E.M.F.'s. Low resistance potentiometers on the

principle given above have been constructed in which mercury contacts have been employed to ensure good contact and freedom from E.M.F. but are obviously inconvenient. A special study of potentiometers for thermo E.M.F. measurements has however been made in Germany, and certain elements have been devised which do not seem to be well known in this country. Chief among these are those of Hausrath and of Diesselhorst. In the former, which is most simply illustrated in Fig. 23, each element consists of a double dial as in the Feussner potentiometer, but the current is carried across from one side of the dial to the other by the contact arm so that the total resistance remains constant while the portion in the lower dials from which the P.D. is derived is varied. The potential leads can be soldered directly to the ends of the lower dials so that the sliding contacts do not affect them. In contradistinction to this device Diesselhorst derives his P.D. from a single coil, the current through which is varied as shown in Fig. 24. Ten equal coils each of resistance r ohms are joined in a continuous ring, the current being led in at stud 0, while the P.D. leads are permanently attached to the single coil between 0 and 9. If the second current lead were connected successively to studs

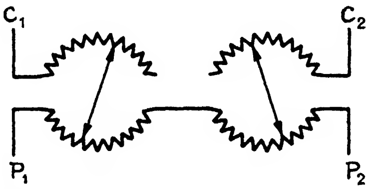


Fig. 23. Hausrath Thermo E.M.F. Free Double Element

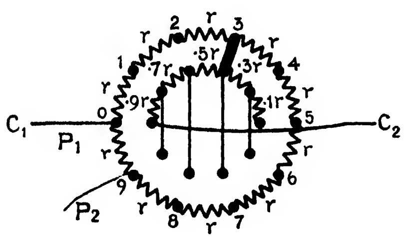


Fig. 24. Diesselhorst Thermo E.M.F. Free Element

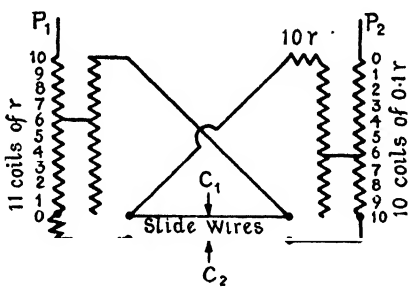


Fig. 25. Diesselhorst 2 Dial and Slide Wire Potentiometer

0, 1, etc., to 9, the proportion of it passing through the coil between 0 and 9 would be ·1/10, 2/10, etc., but the resistance in the current circuit would vary from stud to stud. By having an interior set of studs with resistances as shown this resistance is kept equal and the P.F. across 0 and 9 changes by equal increments from 0 to 9 units.

Two such elements can be connected in series to give a two dial potentiometer reading, say, from 1 to 99 microvolts, but Diesselhorst secured a further increase of range by the ingenious device of connecting two Hausrath elements in parallel, with slide wires between as in Fig. 25. By the use of the double slide wire the resistance of each of the two parallel circuits is kept constant and if such an instrument is made up with coils of 1ω and $\cdot1\omega$ on the two sides and slide wires of $\cdot1\omega$ resistance, and 2 milliamperes of current is passed through it, P.D.'s from 1 to 11,100 microvolts can be directly measured. In view of the importance of high accuracy thermo couple measurements for pyrometry, these devices seem worthy of special attention, and I have just heard that they are now being made by Messrs Tinsley's.

Alternating Current Potentiometers. The great range and scope of operation of the direct current potentiometer led to a desire for its extension to A.C. testing, for which the need is

even greater owing to the limited range of most A.C. instruments imposed by the square law. Various methods of balancing an alternating against a continuous P.D. or current were proposed by Swinburne and others, but they were all inherently insensitive, and no practicable solution appeared in sight until the present writer in 1909 introduced the principle of treating the alternating P.D. as a vector and balancing it by a known P.D. which could be varied both in magnitude and phase, and enabled a telephone or vibration galvanometer to be employed for securing balance. This instrument was put into commercial form by Mr Tinsley in 1910 and has been considerably adopted abroad, as it is the most universal of all testing instruments and is of special value for standardising laboratories where economy in equipment is desirable. It is only suitable for measurements on circuits having a fairly closely sinusoidal supply, but as this condition is now fulfilled in almost all power stations, this limitation is rarely of importance.

A.C. testing with sinusoidal wave forms resolves itself into the measurement of the magnitude and phase angle of vectors, and is akin to surveying in which lengths are measured

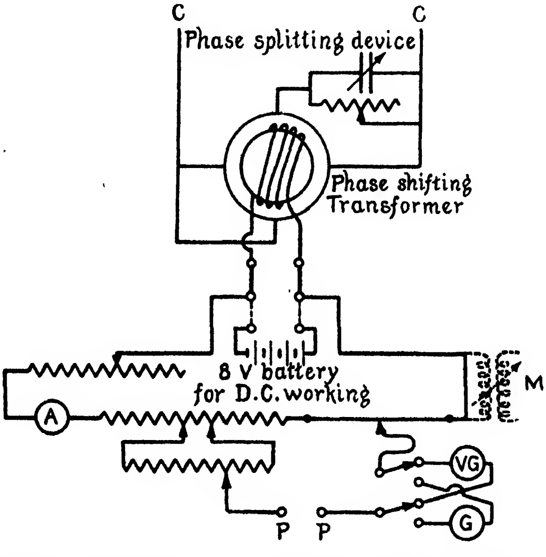


Fig. 26. Drysdale-Tinsley A.C. or D.C. Potentiometer, "Polar" Principle, 1909

by a chain and angles by a prismatic compass or theodolite. If an ordinary potentiometer is fed with alternating current the effective value of which is equal to its normal direct current, the alternating P.D. between its sliding contacts will be the same as the corresponding P.D. with direct current, and can be varied over the same range. This corresponds to the measuring chain, while the electrical theodolite is provided by a phase shifting transformer consisting of a stator with two phase winding excited from the A.C. mains through a phase splitting device. The rotating field thus produced develops an E.M.F. in a rotor with diametral winding, which is constant in magnitude for all positions of the rotor, but changes in phase by the same angle as the rotor is turned through. If therefore the potentiometer is fed from such a transformer through an ammeter and rheostat so that the current is equal to the normal direct current for the instrument, the alternating P.D. between its potential contacts can be varied and read off from its dials as with direct currents, and its phase will vary with the turning of the rotor, so that any P.D. derived from the same supply can be balanced, if a telephone or vibration galvanometer is substituted for the ordinary galvanometer. Fig. 26 shows the elementary diagram of connections of this type of potentiometer, but the actual instrument is provided with a change-over switch which transposes

the connections for either D.C. or A.C. working, and enables the A.C. measurement to be referred directly to a standard cell.

A vector quantity can be defined either by its polar coordinates r, θ or by its rectangular coordinates x, y. The above instrument may be called a polar potentiometer, as it measures r and θ directly, but the rectangular components are readily obtainable from the phase shifting transformer which has cross pointers reading on a cosine scale so that $\sin\phi$ and $\cos\phi$ can be directly read off, and $x = r\cos\phi$ and $y = r\sin\phi$, giving the resistance and reactance components of the P.D. measured. On the whole this principle seems to be the most generally accurate and convenient, as for calibrating instruments the magnitude only of the P.D. and current is required with the highest possible accuracy, and it would be inconvenient and less accurate to calculate it from the components.

On the other hand, the rectangular principle has certain advantages for the measurement of small phase angles with high accuracy, and it is very simple to realise. Fig. 27 shows the simplest possible arrangement, due to Larsen in 1910, in which an ordinary potentiometer is connected in series with the primary of a variable mutual inductance standard M, the secondary of which is in series with one of the potential contacts. If i is the current through

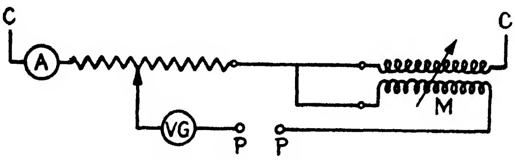


Fig. 27. Larsen Simple Rectangular Coordinate A.C. Potentiometer 1910

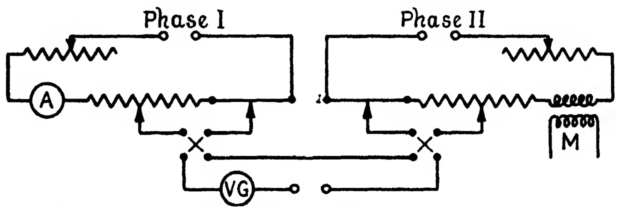


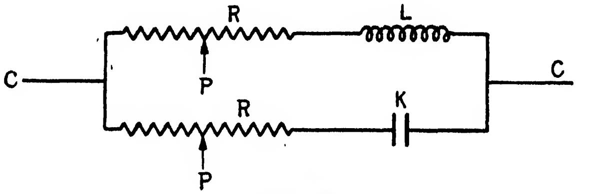
Fig. 28. Gall "Coordinate" A.C. Potentiometer 1923

the potentiometer and r its resistance, a P.D. $V_1 = ri$ is produced in phase with i, but an E.M.F. is developed in the secondary of the mutual inductance, $e_2 = jM\omega i$ lagging or leading by 90°. For any given current and frequency the scale of the mutual inductance can therefore be divided off in fractions of a volt like the potentiometer dials. The writer has utilised this device for the direct measurement of magnetic fields, by connecting the variable mutual inductance as shown by the dotted lines in Fig. 26. This eliminates all frequency or phase calculations.

Mr D. C. Gall has solved the same problem in what he calls his "coordinate potentiometer" (Fig. 28) in another way, by using two ordinary potentiometers fed with currents in quadrature either from a two phase alternator or by a phase splitting device. One of the potentiometers is supplied from Phase I through a dynamometer ammeter and rheostat so as to have its normal current, and the second potentiometer is supplied from Phase II through a rheostat and mutual inductance which develops 0·5 volt in its secondary with the normal current at 50~, ·6 volt at 60~ and so on. The current can therefore be adjusted in the second potentiometer by balancing the E.M.F. in the mutual inductance by the corresponding setting on the first potentiometer, and the instrument is then ready for use. The two P.D.'s from the two potentiometers are in series, and either may be reversed to balance P.D.'s in any quadrant.

More recently Dr P. O. Pedersen has devised a simple and ingenious form of A.C. potentiometer on the rectangular principle (Fig. 29) in which the quadrature relation is independent of the frequency. The two potentiometers of equal resistance R are connected in parallel, one having an inductance L and the other a capacity K in series with it, such that $LK = R^2$. The values of the currents in the two potentiometers, and hence of their readings, of course vary with the frequency, but can be calculated without difficulty.

The applications of the A.C. potentiometer are legion, and although, like other universal instruments, it may not be the best or most convenient device for any particular test, there is hardly any direct or alternating current measurement which cannot be made with it, with sufficient accuracy for most practical purposes. Its technique requires a little experience to become thoroughly familiar with its applications, but when once the simple principles are grasped it certainly forms the best all-round equipment for a testing laboratory, and the ability to measure direct or alternating P.D.'s from a few microvolts to thousands of volts at frequencies from 20 to 2000~ and currents of even greater range with a few volt boxes and resistance standards, to an accuracy of about 0·1 per cent.; apart from power, inductance, capacity, and magnetic field measurements, is in itself an enormous advantage. It is somewhat surprising that these features should have been much more appreciated by the Japanese and others abroad than in this country, and I may perhaps be excused for calling attention to it.



$LK = R^2$

Fig. 29. Pedersen A.C. Potentiometer, Rectangular Principle, 1919

Instruments for Inductance and Capacity Testing.

Even thirty years ago inductance and capacity measurement had reached a high degree of accuracy, thanks to the pioneer work of Maxwell and of Professors Ayrton and Perry, and their variable standard of inductance was an instrument of very high precision which has hardly been surpassed up to this day. The secohmmeter which they introduced for both absolute and comparison measurements was also a most valuable instrument before the days of oscillators and vibration galvanometers, and the writer knows from considerable experience what good work could be done with it. Nevertheless, alternating current testing methods are superior when dielectric losses have to be measured, and the introduction of the long range variable mutual inductance standard by Mr A. Campbell had the advantage not only of higher accuracy of construction and very long range, but of passing through a zero value, whereas it is extremely difficult to get more than a tenfold range with a variable inductance, and the variation of resistance of its copper coils with temperature is often an inconvenience. Modern testing with high-frequency currents has called for greater perfection in the non-inductivity and better screening of the resistance coils in the bridge methods, and the compensated screening methods of Schering and others have proved of great value. The great demand for inductance coils of low power factor for radio work has also led to special forms of open windings to reduce the internal capacity to a minimum.

As regards condensers, the mica and paraffin paper condensers which were developed for cable work have persisted almost unchanged for forty years or more, and are on the

whole remarkably satisfactory. The chief advances have been in the various forms of dial condensers, which although simple in principle have required a great deal of working out in order to reduce the capacities of the contacts to a minimum, especially in the low capacity dials, while the advent of radio work has caused an enormous demand for variable condensers of the rotating vane type, which although in the majority of cases of simple construction, have also been developed as precision condensers. It is only recently, however, that the various factors and true meaning of the capacity of condensers has been appreciated, and the recent work on the extension of the range and screening of vane condensers at the National Physical Laboratory is of great value. As regards condensers with "square law" or frequency scales now being largely made for broadcasting work it is open to question as to whether the shaping of the vanes to secure the desired law is the correct procedure, or whether it would not be better to introduce cam gear between the spindle and pointer, so as to give the required motion with the ordinary semicircular plates, which give the maximum capacity for given overall dimensions.

Iron Testing Instruments.

The number of instruments for the magnetic testing of materials is legion, and only a few leading features can be referred to. Until a few years ago most of them were based on the classic work of Ewing—the magnetometer, ballistic galvanometer, traction methods and magnetic bridge, with the addition of the rotating hysteresis tester and the wattmeter method, but although all these methods were capable of giving good results they were chiefly laboratory methods requiring a good deal of setting up, and limited to tests on long bars or ring stampings. The testing of the latter by the wattmeter method is quite satisfactory, but for the determination of hysteresis loops two great advances were the Evershed method of measuring the change of magnetisation from the maximum of the cycle at each reading, and the invention of the fluxmeter by Grassot in 1904. The latter instrument was a valuable addition to our stock of scientific instruments, and has quite ousted the ballistic galvanometer except for very delicate measurements.

The simple principle of this instrument is that if a magnetic flux is introduced into a circuit, part of which is free to move in a fixed magnetic field, this part tends to move so as to keep the total flux constant, and will do so if either the circuit is of no resistance or there is no restraint to the motion. In theory, therefore, the conditions for high sensitivity of such an instrument are opposite to those for a sensitive galvanometer, as the fewer the turns in the coil and the weaker the field it moves in, the more it will have to deflect in order to include as many opposite linkages as those introduced. In the Grassot fluxmeter a rectangular moving coil is employed in a permanent magnet field, and is suspended by a very fine torsion wire from spring supports, but the resistance of the suspension is necessarily high so that the coil must have many turns, and the instrument is therefore not very sensitive, the usual constant being about 10,000 Maxwell turns per scale division. This is, however, amply sufficient for most magnetic testing. The principle of the fluxmeter is so valuable, however, that it seems worth while to point out that it is equally applicable either to moving coil or moving magnet systems, and it may be suggested that a moving magnet system might lead to a more sensitive type of instrument. If we have a rectangular coil of a single layer of fine wire fixed inside a ring of nickel-iron stampings, and a rectangular cobalt steel magnet moving inside it with the minimum of clearance, one face of the magnet being polished to act as a mirror, it should form a sensitive reflecting fluxmeter. The whole movement should be mounted in a nickel-iron case to eliminate control by the earth's field, and it might be well to duplicate it so as to be approximately astatic.

As regards permeameters there has recently been a tendency to abandon all the other types, with their liability to errors from joints, in favour of what may be called magnetic

potentiometer methods. If we have a uniform iron ring wound with a uniformly spaced toroidal coil, there will be no difference of magnetic potential between any parts of the ring, but with a straight bar and yoke with a magnetising coil on the former a certain unknown and variable M.M.F. is required to overcome the reluctance of the joints and yoke. By adding an additional magnetising coil on the yoke, or two additional coils at the two ends of the bar, it is possible to reduce two points of the bar to the same magnetic potential which can be tested by having a U-shaped piece of iron with a search coil on it which makes contact with the test bar near its two ends. The extra magnetising coils can be connected in series with the main one and shunted with a rheostat until reversal of the current gives no effect on a galvanometer on the testing search coil, in which case the two points on the bar are at the same magnetic potential, and H is simply $4\pi/10$ times the ampere turns per cm. between the points; while the induction can be determined by a fluxmeter connected to a search coil on the bar in the ordinary way. It appears probable that this will become the standard method of testing magnetic materials in bar form in the future, and it offers up opportunities for testing the magnetic qualities of castings or forgings. About twenty years ago this was a burning question with dynamo makers owing to the variable magnetic qualities of their castings, and the writer therefore designed a "plug permeameter" in which a special drill was used to cut a conical blind hole in the casting with a pin of standard diameter left standing in it.

A conical split iron plug carrying magnetising and search coils could then be forced into the hole, gripping the pin, and making a miniature bar and yoke permeameter in the casting itself, and the test could be carried out by an ammeter and fluxmeter in the ordinary way. Owing to the small ratio of length to diameter in the specimen (·5″ to ·1″) end effects were of considerable importance, and allowance had to be made for them; but there would seem to be no reason now why a pin of say ·1″ diameter and 1″ long should not be drilled out of the casting or forging by a hollow drill and tested in a small yoke by the new magnetic potential method, and it should be possible to construct a very simple and reasonably accurate permeameter on these lines.

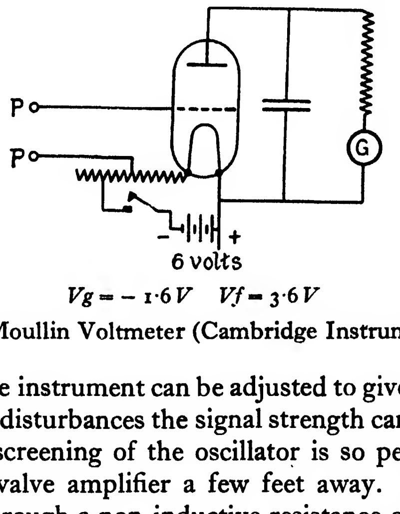
Instruments for High Frequency Measurements.

Despite the astonishingly rapid progress of radio transmission, measurements and measuring instruments in connection with it still seem to be in a very backward state, and it would seem that the time must soon come when quantitative measurement must be conducted on a large scale in order to improve the efficiency of the systems. No doubt this need would have been felt much sooner but for the wonderful amplifying power of thermionic valves, which has rendered it easier to obtain reception by the addition of another valve or two, rather than by laboriously trying to improve the efficiency of transmission. This is hardly a sound policy however, as high sensitivity of reception means magnification of atmospheric and other disturbances, and we may be sure that before long attention will be concentrated on sending out beams of intense power with the maximum efficiency.

The need for satisfactory frequency or wave meters was the first to be felt, as satisfactory C.W. reception depends greatly on constancy of wave length. Such wave meters are generally simple resonant circuits of low resistance in which the resonant frequency is varied by a variable standard condenser or inductance, and resonance is obtained either by observing the maximum signal strength or by causing them to oscillate and obtaining exact tuning by observing the interference note or beat. During the last few years very accurate frequency standards have been developed employing the "Cady effect" of quartz piezo-electric resonators, which are very valuable for maintaining a constant frequency of transmission.

For current measurements nothing so far has been found which is superior to the thermo-

junction and millivoltmeter or galvanometer, and it is satisfactory to note that self-contained ammeters are now obtainable on this principle which cover the range from a few milliamperes to several amperes at radio frequencies. So far as transmission is required these meet requirements, but for the minute currents at the receiving end no simple direct reading instrument is available, although useful measurements can in some cases be made with a crystal rectifier and ordinary galvanometers. The high resistance of such rectifiers is however a serious drawback, and up to the present the best method of approximately measuring the P.D. and current in receiving circuits is by the "Signal strength measurer" of Messrs B. S. and F. D. Smith. In this instrument a carefully screened oscillator is employed to produce an oscillating current of the same frequency as that of the received signal and is connected to a simple resistance form of "artificial line" by which the P.D. derived from it can be altered by steps of equal ratio. This is preferable to the ordinary potentiometer on account of the large range required. In the instrument as at present made there are 34 steps each having a ratio of $1/\sqrt{2}$ or 71 per cent., the resistance at the input end being only 0·1 ohm, so that with a current of 10 milliamperes the P.D. can be varied in steps of 70 per cent. from 1000 microvolts down to $1000/2^{17}$ or ·0076 microvolt. By means of a change over key this P.D. can be substituted for that in the receiving circuit and used with the ordinary amplifier and head phones, and by throwing the key successively over to one or



$Vg = -1{\cdot}6\,V \quad Vf = 3{\cdot}6\,V$

Fig. 30. Moullin Voltmeter (Cambridge Instrument Co.)

other circuit, the P.D. from the instrument can be adjusted to give the same signal strength as that received. If there are no disturbances the signal strength can be matched to an accuracy of about 15 per cent. The screening of the oscillator is so perfect that it causes no disturbance whatever in a six valve amplifier a few feet away. Currents can of course be measured by passing them through a non-inductive resistance of say 1 ohm and measuring the P.D. across it. At present this instrument seems to offer the best means of making measurements of received signals.

For high frequency P.D. measurements of the order of a volt, sensitive low capacity electrometers of various forms have been employed with some success, but one of the most useful instruments for radio measurement is the valve voltmeter of Mr E. B. Moullin. There are two types of this instrument, the one shown in the diagram (Fig. 30) reading from 0 to 1·5 volts without H.T. battery, and the other from 0 to 10 volts with a 70 volt battery substituted for the resistance in the galvanometer circuit. In the former, as shown, the dull emitter filament which requires only 3·6 volts for the low temperature at which it is run is connected to a 6 volt battery through a rheostat, and one of the terminals *P* to which the P.D. is applied is tapped off this rheostat, so that when the two terminals are bridged the grid potential is 1·6 volts below that of the negative end of the filament. The galvanometer is of the single pivot type and is provided with two zero marks, one its true zero for no current and the other to which the pointer should deflect when the terminals *P* are short circuited and the filament current is adjusted to its correct value by the rheostat.

On then applying the P.D. to the terminals P the voltage is indicated directly on the upper part of the scale. This instrument has been found most valuable for measurements within its range, and it is to be hoped that the principle may be extended by the use of a resistance capacity amplifier so as to serve for very low P.D.'s. Unfortunately, thermionic valves, however valuable they are for the magnification of weak signals, have not yet arrived at the stage of being reliable metrical devices, but it is to be hoped that a greater approach to constancy of performance will come about before long.

The need for accurate and portable instruments for measuring high-frequency P.D.'s and currents down to a few microvolts or microamperes and the corresponding power appears to be very great, and it is to be hoped that they will be forthcoming in the near future.

One great recent advance however which has been made in recent years is in the direct recording of high-frequency phenomena by the Cathode-ray Oscillograph. It has long been known that a stream of rapidly moving electrons in a high vacuum can be deflected either by a transverse electrostatic or magnetic field, and this principle has been developed into practical oscillographs by Braun, Dufour, and Wood. The Braun tube consists of a sealed bulb having an incandescent filament with a spot of lime at one end from which electrons are projected through a small aperture in a metal disc forming the anode and pass between one or two pairs of deflecting plates to fall on a fluorescent screen on the large opposite end. The P.D. to be investigated is applied to one pair of these plates, and causes the beam and illuminated spot to oscillate, while a second transverse movement is given to the beam by another P.D. across the second pair of plates, and this movement can be varied as required, so as to give either a wave form with uniform time scale, or a Lissajou figure. Practical forms of such oscillograph tubes have been introduced by the Western Electric Co. and by Messrs Edwards and Co. and are very useful for the observation of cyclic phenomena such as hysteresis loops.

M. Dufour and Dr Wood have however developed cathode-ray oscillographs of a more elaborate type by which photographic traces of extremely rapidly varying electrical phenomena can be obtained. The oscillograph of M. Dufour was originally intended for radio investigations up to frequencies of a million or so a second and accordingly was of the high voltage type having a cold cathode and about 50,000 volts between the cathode and anode, giving a high velocity stream of electrons of great photographic intensity; while Dr Wood's was designed for somewhat lower frequencies, and had an incandescent lime-coated or thoriated filament as cathode with a P.D. of about 2000 volts, giving sufficient photographic effect on Schumann plates with a deflection of a centimetre for about 30 volts between the deflecting plates. This apparatus was made entirely of metal, with the exception of a small bulb containing the filament and an inspection window for observing the spot on the fluorescent screen; and contained a rotating plate holder by which six Schumann plates could be exposed in succession before opening the apparatus for developing and re-charging the plate holder. The Cathode ray Oscillograph has already reached a point where it must be regarded as a most valuable piece of apparatus for all high-frequency or rapidly variable phenomena, and its energy sensitivity is of course greatly superior to that of all other types. If the sealed form could only be made with sufficient intensity to allow of photography on an external rapidly moving film, it would probably displace all other types; and it may perhaps be possible to do this by employing a concave cathode as in an X-ray focus tube, but the question then arises as to whether any fluorescent material would stand the intense bombardment without rapid disintegration. It is to be hoped however that this will be followed up.

In conclusion I venture to hope that this necessarily extremely imperfect summary of progress and possibilities in the design of electrical measuring instruments may prove of

some service both to scientific workers and to instrument manufacturers—to the former by calling their attention to the comparisons between different types of instruments and the more recent advances; and to the latter by stimulating them to review the whole position and consider in what direction simplifications and advances may be made. Although healthy rivalry and diversity are most valuable in the early stages of an industry, a time is bound to come when certain types show definite superiority; and in view of the immense diversity of electrical instruments at the present time it seems highly desirable that we should take stock of our position, eliminate the less promising types, and take some steps towards standardisation and mass production of those instruments which have been found to be practically developed to their limit. I certainly think that the time is already ripe for the consideration of standard types of résistance boxes, bridges, and potentiometers on somewhat the lines I have indicated, and of moving coil indicating instruments and galvanometers. But on the other hand, I am firmly convinced that the advent of the new magnetic materials will enable almost revolutionary improvements to be effected in soft iron and other instruments, and I hope that these few suggestions will be taken up by some of the manufacturers and result in further progress and economy*.

The history of British electrical instruments as a whole is a fine one, and it is to be hoped that we shall continue to add to its lustre.

LABORATORY AND WORKSHOP NOTES

MANIPULATING GLASS. By C. V. BOYS, F.R.S.

[*MS. received*, 22*nd April*, 1927.]

I AM tempted by Mr B. Brown's Note on Drilling Holes in Glass in the March number of the *Journal of Scientific Instruments* to offer you some supplementary notes on that and cognate subjects.

Mr Brown raises three matters—drills for glass, camphor in turpentine, and filing glass—on each of which I believe I can give useful additional information.

Drills for glass. Holtzapffel† says (footnote, vol. II, p. 553) glass may be drilled with the tool illustrated in Fig. 470, i.e. the double cutting pointed drill of the drill bow, or with that in Fig. 471, in which the four facets meeting in a point are replaced by a pair of curved facets forming a curved diametrical double cutting edge, and he says lubricate with turpentine. He does not mention camphor. Threlfall in his *Laboratory Arts* treats of the drilling of glass in a manner which makes one almost believe he is writing of metal. He uses the ordinary Morse twist drill with lots of kerosene and he discusses the relative merits of this lubricant and the camphor-turpentine mixture of ancient tradition. He cannot find any superiority of one over the other. He also mentions the use by Faraday of a three-square file ground smooth and with the tip broken off, but in my copy of Faraday's *Chemical Manipulation* I can find no mention of this either in the paragraph cited or elsewhere.

Coming now to my own ideas and practice, I look upon that obtuse but short cross edge at the end of a single cutting flat drill or of a twist drill as most objectionable when drilling glass. It serves a useful purpose if a twist drill is used for drilling brass (which is wrong),

* Since the above was written Col. Edgcumbe and Mr Ockenden have given a paper before the Institution of Electrical Engineers in which they describe important advances in moving iron instruments and instrument transformers which they have made on the lines above indicated.

† *Turning and Mechanical Manipulation.*

for it meets with so much opposition as to prevent the acute edges from digging in, as they are so prone to do when the said obtuse edge breaks through.

It is this blunt cross edge which requires so great a thrust when drilling iron or steel and which is advantageously relieved by the use of a small leading hole. In the case of glass it gives rise to so much stress as to limit very greatly the speed of drilling, and the sudden change when it breaks through may very easily lead to a fatal crack. The four facets of the double cutting drill recommended by Holtzapffel meet in a point, and so this defect is avoided, but the double cutting drill is a futile sort of design, as the facets must make an acute angle with the work and much too great an angle of relief to give due support to the edge. No tinkering with the angles can put it right, for whether more or less one or other fault is magnified. It is now more than 50 years since I wanted to drill a hole through the knob of a bell jar for a beehive to afford ventilation, and with the considerations mentioned above in mind I made a drill of tool steel which I still look upon as the ideal steel tool if diamond is not available. This I made as follows: I heated the end of a piece of Stubbs steel wire red hot and with one blow on an anvil slightly spread the end. Then I filed it to the shape of a flat single cutting drill, with this difference, that I filed the flat faces at the very end slightly convex so as to meet at a point with the two cutting facets. This form gives a low angle of relief, a right angle between the cutting face and the work, and there is no obtuse cross edge to burst through the glass. Such a drill must be used dead hard with appropriate lubricant. To prevent damage in hardening it is well to melt cyanide of potassium in the drill, or soap, and keep the blow pipe flame off the edges, or better not use a blow pipe at all, and quench vertically in really clean water. I have never used mercury, but this is recommended by Threlfall. I cannot now remember if I ground that drill before or during the drilling, but I do remember well that it cut through the glass very quickly and I had no trouble whatever. The hole was about $\frac{3}{16}$ inch in diameter and about an inch through.

Another form of drill for glass can be made in a very few minutes by grinding a very acute three sided pyramid at the end of a file, using only the lightest pressure on the stone to avoid heating even to a straw colour. This is suitable for drilling conical pits in glass or for scratching a hole through window glass or through glass tube.

Lubricant. Whatever may be the true theory of the different lubricants used in cutting metal, my own belief is that for cutting glass all that is wanted is a mobile liquid of low surface tension so that it may instantly insinuate itself and wet everything up to the cutting edge and wash away the dust. Turpentine used to be the most generally accessible liquid having these properties, but Threlfall's kerosene or paraffin is now even more easily available. I have not tried tetrachloride of carbon or acetone or other liquids having the two properties mentioned, but I should expect them to do as well. Why, then, camphor in the turpentine? This is a tradition which I have known ever since I was at school and I have often wondered how it originated. Can Mr B. Brown throw any light on this? I mean, has he found that camphor really improves the turpentine, or is he merely carrying on the tradition? It has seemed to me possible that someone looking for turpentine in a hurry in order to drill glass may have been a firework maker, and found his supply of camphor in turpentine which is used in making tailed stars for rockets, and used this as the only available turpentine. Then in describing the process the camphor would be mentioned and ever after it would be looked upon as essential. Of course in my case, I had the camphor solution at hand for making tailed stars and so I used it or plain turpentine indifferently.

Files. The ordinary three square file of the tool shop is not really three square at all but six squares, for after the file maker had cut the three flat faces with teeth he cut teeth along the corners. Such a file may cut notches in metal better than one in which the final corner teeth have not been cut, but it is useless for notching glass tubes before breaking

them. The essence of such a cut is a notch deep and sharp at the bottom, and this can only be cut by a file in which only the three faces have been cut with teeth. The corners then cut deep into the glass. The slender and somewhat irregular hard points along the edges which give the glass notching file its value are tender and are apt to be rubbed off by the unskilled user of the file. He rubs the file quickly backwards and forwards on the glass with equal pressure on the two strokes and the file is soon spoilt. The tender hard points will stand up to a heavy slow forward cut, as they are supported from behind, but unless the back-stroke is without pressure, being unsupported from behind, they break away. So important is it that the notch should be deep and sharp that it used to be general practice to use an old razor blade for this purpose. Using tools on glass is generally very bad for the tool, and Threlfall says that Morse drills are ruined in the process. Similarly a razor blade after notching glass would serve its original purpose very badly.

Leading cracks. A small size of glass tube, after being properly notched, will generally break square at the notch if pulled or bent in the direction to open the notch. As the tubes are larger the process becomes more hazardous. Of course the lapidary's steel slitting disc armed with diamond dust will always make a clean cut right through, but this valuable tool, which ought to be in every general workshop, is rarely found except in a geological laboratory. It becomes desirable therefore to do something to induce a crack to take the desired direction from the primitive notch. Notching all round is a mistake; a single notch made with one firm stroke is best, and no lubricant is required. Then a fairly thick copper wire, say 14 gauge, in a handle, with the end bent to the curve of the tube, heated dull red and laid on just beyond the notch in the desired direction and held still, will often start the crack. At the first starting of the crack the minimum of heat should be used, as otherwise it may get out of hand. If a crack does not appear, touching the notch with the wet finger will help. When once started it will follow the hot wire obediently as desired and the tube may be severed square across or at an angle if it is to be used for a liquid prism.

It must be remembered that glass tubes are like all hollow glass ware. The interior is in a state of tensile stress and the exterior notches are not so very potent. On the other hand, if a glass tube can be cut on the inside and warmed on the outside it will be far more easily severed. A glazier's diamond set at the side of the end of a rod, with an adjustable stock like a depth gauge, is the perfect tool for severing tubes from the inside, or a dead hard steel point or edge of corresponding form may be used, but it does not last long. I have made very clean square cuts in glass tubes by turning an iron disk about $\frac{1}{8}$ inch thick, with a V edge of such a size as just to go in, and screwing it on to the end of an axial rod with stock. Then, notching the tube on the outside and inserting the disk made dull red hot to the identical depth, the state of stress is reversed and the exterior becomes tense. Then the break follows almost immediately and perfectly square. Quite narrow rings may be severed in this way, suitable for making cells.

The state of stress in a glass tube could be reversed by heating the part where the cut is required to a barely visible red heat and then blowing through the tube with bellows to cool it from the inside. An external notch then should be very effective.

Shanks and nibbling glass. Chemists used to be familiar with the use of a key with a suitable ward for crushing the edge piecemeal of a clock glass, so as to make a notch for a glass rod in a beaker covered by the glass. The action of the key is not to get hold as by a pair of pliers and break a bit out. That would instantly start a crack right across the glass. The key merely crushes the edge locally and the process is surprisingly rapid. The softness of the metal is an essential factor. The optician, in bringing rough lenses and other things to the desired shape, uses what is equivalent to a key with a ward of variable width, that is, a pair of soft iron square rods very loosely hinged at one end and with scissor loops at the other. With this tool glass vanishes in grit, and provided there is no attempt to get hold of

a piece of the glass and break it out, the process is certain and rapid beyond all expectation. This however is no good for tubes. Shanks is the name of the tool.

Diamond tools. The most generally known diamond tool is the glazier's diamond, which does not need description. The essence of this is the curved natural edge in the extra hard exterior surface of the stone. The diamond is mounted and should be so held that the curved edge is in line with and tangential to the cut. With a light pressure (to be determined by trial) and a rapid stroke the diamond glides over the glass almost silently or with a gentle singing noise. If held more steeply, so that the actual point bears on the glass, both the sound and the appearance of the mark are entirely different. A conspicuous scratch takes the place of a fine line. It is instructive to make a diamond cut in the back of an old photographic negative and examine it immediately in full sunlight, by the aid of a lens. The action of the edge is to tread down a surface line of the glass into the interior where it is swallowed, and it produces a bursting lateral pressure. This may at once develop a crack part way through the glass, or there may at first be no visible crack. It is then that the full sunlight shining across the line shows up what is happening. A fine line on the surface is visible and its shadow in the photographic film. Gradually the shadow of the line broadens as an actual parting of the glass develops, and the light which did fall where the shadow is now is reflected on to the film on the other side. After a quarter of a minute or so the crack is fully developed. When therefore a bending force is applied to the glass at one end of the crack, in a direction to open it, the still unsevered glass is progressively divided by the extension right through of the initial crack, and the glass has been cut.

Where such thin glass as microscope cover glass is required to be cut a glazier's diamond is no good. For this a sharp splinter of diamond, called when mounted a writing diamond, is perfect. It is not difficult to prepare tools of the writing diamond type, but much finer. Take a piece of bort—a kind of spherical mass of diamond with a radial crystalline structure—and if a diamond crushing mortar is not available place it within a ring on a hardened anvil. Hold a flat ended hardened steel punch on the piece of bort and strike it with a hammer. The minimum stroke that will break the diamond should be employed, and this can be led up to by degrees. It is surprising what a blow a diamond will stand. As Sir William Crookes so beautifully showed, a diamond crystal may be placed between two jaws of mild steel and these pressed together until they have swallowed the diamond, which may then be taken out unharmed, leaving two perfect half impressions of its form in the steel. When the bort has been broken a multitude of fine diamond splinters will be found, and suitable points can be picked out and slipped into holes drilled in brass wires, which should then be pinched to retain the points. The easiest way to secure them is to wet the hole with a drop of chloride of zinc solution, apply a speck of soft solder and heat gradually until the solder flashes into the hole and envelopes the diamond, leaving only a point outside. Such tools properly mounted and moved, and resting on the glass with an almost infinitesimal pressure, may be used for ruling the finest lines. If such a line is examined immediately with a microscope the glass shavings may sometimes be found in the form of perfect helices, like shavings made with a plane held askew.

The soft steel disks of the lapidary for slitting, and metal tubes for cutting out larger holes in sheet glass than can be drilled, are armed with diamond dust by pressing it in to the edge or end with the clean black surface of a flint. While emery or carborundum may be used in this way the materials are so inferior to diamond dust that this is greatly to be preferred.

Holtzapffel, in describing the drilling and slicing of hard materials by the use of tools armed with diamond dust, always refers to the lubricant as the "oil of brick," which was valuable because it was so extremely limpid.

Oil of brick, so far as I have been able to find out, was olive oil into which a red hot brick had been immersed. Soap and water is also used and lubricant of some kind is essential.

Diamond tools are used for trueing emery wheels. If the wheel is turned slowly and the diamond is fed very slowly the emery crushes before it, and it is marvellous, after a diamond has travelled in this way some miles over the emery under considerable pressure, to find the stone entirely unmarked by the process. It is equally astonishing to see the diamond end stone of a chronometer balance, on which the fine hardened steel point carrying the weight of the balance wheel has been twisting backwards and upwards a million times every three days for years and years. By the aid of a lens the polish marks on the diamond may be made out, but not a mark to indicate where the pivot has rested.

Ebonite is very destructive to steel tools, so that diamond tools are preferable in making fountain pens, for they then last in adjustment, whereas steel tools have to be ground so often that the cost of constant adjustment is greater than the initial great expense of large diamond tools. Why is ebonite so destructive to steel edge tools that it is best not to use steel taps upon it, and yet taps made from ordinary brass and roughly filed up work perfectly?

Of the two books that I have mentioned the first three volumes of Holtzapffel are a classic. For the amount of information and the scientific nature of all the descriptions where the principles on which success depends are so fully considered, these three volumes are unequalled. The fact that they were written before the days of the ubiquitous American tool in general is no detriment; they provide a fundamental education, and they should be read by everyone who aspires to be an experimental constructor. Threlfall's *On Laboratory Arts* is on a much more modest scale and it is far more restricted in subjects treated. But it is written also by a person with the instinct of manipulation and construction, and it is specially written from the point of view of a physical laboratory. A copy should be found in every laboratory workshop.

LAPPING SCREWS. By B. BROWN, B.Sc. (Eng.)

[*MS. received*, 1st *April*, 1927.]

Sometimes a screw has to fit into its nut very accurately, whilst still there is no importance attached to the actual dimensions of the parts. It is generally difficult to accomplish this by the use of the ordinary threading tools because of the existence of pitch error. If the screw be made of such a size that it just enters the nut it is almost sure to bind at the far end. On the other hand, if it is a snug fit when full home it becomes slack when engaged over only a portion of its length.

To get the desired type of fit the screw will have to be altered after the cutting of the thread. This operation is usually one of lapping. The ordinary kind of screw laps are troublesome to make and their use is only justified where the accuracy pertains to gauge work. Following is given a method of lapping which takes no time for preparation and gives good results.

Tabulated figures for the screw in question should be consulted, and from them found the core radius and the "best" diameter of needle for the measurement of the effective diameter. Next a wire chart should be examined and sizes chosen to correspond with those just mentioned. Generally there will be a slight difference, and the nearest larger size should be adopted. It is not very important from what metal the wire is made, though brass or copper will be quicker in action than steel.

The screw should be mounted in a lathe and driven at a speed depending upon the diameter, but in any case not too fast. A length of the wire corresponding in diameter to the effective diameter needles should then be taken and coated with an abrasive paste—

carborundum and oil—and run up and down the threads while a suitable pressure is applied. From time to time the screw should be tried into the nut so as to see when lapping has proceeded sufficiently far. With a little experience the wire can be given a lateral pressure which will help to correct for pitch error.

The core diameter may be reduced in a similar manner, using the other size wire. Always, however, the process of reduction should be started with the effective diameter, since there the trouble will most likely find root. Ordinary taps provide clearance at the tops and roots of the threads.

It may happen that there is need to reduce the top diameter. This may be done with a piece of very fine emery paper stretched over a strip of wood. The tops of the threads will be flat, but it is of no importance and will not affect the fit so long as the effective diameter and pitch are within reasonable limits.

REVIEW

The New Heat Theorem. By W. NERNST. Translated from the Second German Edition by GUY BARR, B.A., D.Sc. (Methuen, London, 1926.) 8vo. $9 \times 5\frac{1}{2}$. Pp. xvi + 281. Price 12*s*. 6*d*. net.

Although we have met brief accounts of the New Heat Theorem in several of the modern works on Physical Chemistry and Thermodynamics, it has been difficult to assess the real importance of the developments which have been brought about by the Nernst school. For this reason we welcome this translation, which gives us first-hand information.

The book opens with a brief introduction showing the point in the classical thermodynamics from which the new theorem is developed, namely, the equation $A - U = T\frac{dA}{dT}$, where U and A are the two fundamental thermodynamical functions, total energy and free energy. The author discusses the constant of integration that arises when this equation is solved, U being a known function of T, and arrives at the conclusion that this all-important constant is determined by the limiting conditions that Limit $\frac{dA}{dT}$ = Limit $\frac{dU}{dT}$ when $T = 0$.

The methods by which this conclusion can be tested against experimental results are discussed, and it emerges that a knowledge of the specific heats of substances at low temperatures is required; there follow three chapters on the experimental determination of these quantities, and a brief examination of Dulong and Petit's Law, and the specific heat formulae proposed by Einstein, Debye, and others.

Returning to the theoretical aspect, the theorem of the unattainability of the absolute zero is demonstrated, but here the argument is not clear, and we feel that the author, in his efforts to overcome existing opposition to his views, has hindered, rather than helped, the reader. The later chapters are concerned with the application of the theorem to various problems, and with its extension to the gaseous state and the limitations inherent in this extension.

There is an Appendix giving definitions of symbols and numerical values of physical constants, but we noticed in the text that the letters k and F were each made to serve two purposes. This is unnecessary and misleading. Numerous references to the author's *Theoretical Chemistry* are given, and we advise the intending reader that he will find his progress impeded if he has not a copy of that work at hand. The references in this translation follow the pagination of the latest English translation of the *Theoretical Chemistry*. (Macmillan, 1923.)

The work of the translator is well done and we notice only two errors in type.

V. T. S.

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A VERSATILE INDUCTOMETER BRIDGE.

By ALBERT CAMPBELL, M.A.

[*MS. received*, *16th March*, 1927.]

ABSTRACT. The author's Capacitance Bridge is described, by which quick measurements can be made of capacitance over a very wide range (1 $\mu\mu$F to 30 μF). Although primarily designed for this purpose, it can also be used for a variety of other measurements, *e.g.* of small mutual and self-inductances and of large self-inductances extending to many henries, such as occur in intervalve transformers. Effective resistance and frequency can also be determined, and very high and low resistances approximately measured.

1. INTRODUCTORY

IN a paper recently read before the Physical Society* the author described an inductometer bridge designed for the convenient measurement of capacitance. The instrument is arranged so as to be useful for a variety of other measurements of inductance and resistance, which will be described here.

2. GENERAL DESCRIPTION OF THE INSTRUMENT

The bridge, which is shown diagrammatically in Fig. 1, consists of a mutual inductometer connected into an equal-arm bridge (ratio arms S, S). The current from the alternating source A passes through the two primary coils and enters the bridge through the slider of the potentiometer rheostat B, H and K consisting of two secondary coils identical in resistance and self-inductance. In the same arms as H and K there are equal resistances P and Q, which can be varied in steps simultaneously by a double switch, the last position of which opens each circuit. The detecting instrument G is a telephone for the higher audio frequencies (300 ~ per sec. and upwards), or a vibration galvanometer for lower frequencies, such as those of house lighting supply. For some of the resistance measurements described below, a D.C. galvanometer can be used.

In the present model the inductometer has a range of mutual inductance from − 5 up to 150 μH, *i.e.* when measuring self-inductance a scale-range of − 10 to 105 μH, extended by two fixed steps to 305 μH. The scale is marked to read self-inductance L directly in microhenries. For convenience of zero-setting (to allow for leads, etc.) a small inductometer reading from − 2 to + 2 μH is arranged in series with the main one. The slide-wire rheostat at B, also provided with a zero-setting device, has a range on each side of zero sufficient to balance (and measure) any difference of resistance between the P and Q arms up to a maximum of $\pm$ 0·6 ohm; and by a shunting switch the range can be reduced to $\pm$ 0·06 ohm, each small division then being equal to 0·001 Ω. The equal resistances P and

* *Proc. Phys. Soc.* 39, 145, 1927.

Q have the series of values $\sqrt{10}$, 10, $\sqrt{1000}$, 100 and $\sqrt{100{,}000}$, 1000 and $\sqrt{10^7}$ ohms, the squares of these numbers being 10, 100, 1000 ... up to 10^7. The reason for this arrangement of values will be explained later.

Fig. 2 shows a top view of the instrument, which is made by the Cambridge Instrument Company, Limited. In front of the main scale are the switch for the fixed inductance steps (V) and the zero-setting inductometer (W) (on the right). Behind are the rheostat (B) (with white scale) and the range switch (T) for altering P and Q.

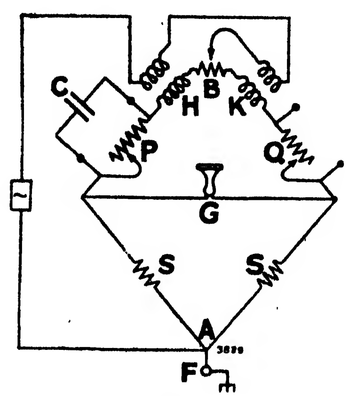


Fig. 1

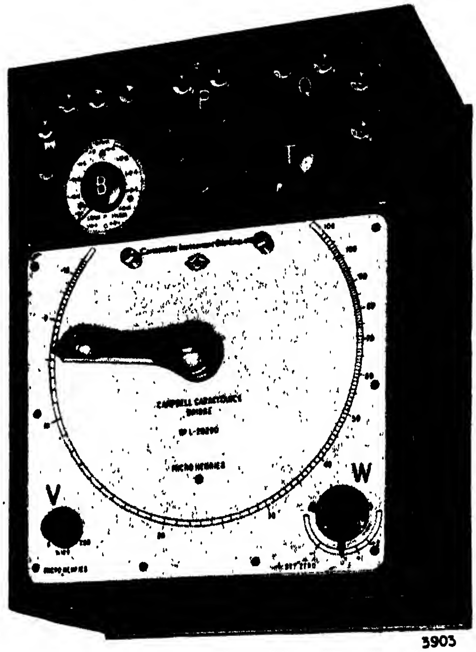


Fig. 2

3. The Inductometer

The most novel part of the instrument is the main inductometer, which is of a new type*. In the author's earlier inductometers a movable coil was arranged to turn with its mean plane parallel to the planes of two fixed coils, and midway between them. The maximum angular scale (of mutual inductance) in this case was only about 160°.

In the new system, shown in plan in Fig. 3, two vertical coils are used, D being fixed, while E (carrying the pointer) is rotatable about a vertical axis X. As will be seen from Fig. 2, this system gives a very great extension of angular range, the actual example shown in the figure reaching about 260°. An even more important advantage is that it allows a scale to be obtained, which for nearly the whole of its range has *almost constant percentage accuracy of reading*. If the scale in Fig. 2 be examined, it will be found, for example, that the angular measurements from 10 to 20, 20 to 40 and 40 to 80 are all approximately equal. Thus from 10 upwards the scale is nearly the exponential one given by the equation

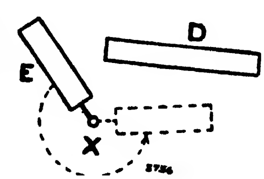


Fig. 3

$$M = a\epsilon^{\theta},$$

where M is the mutual inductance at angular reading θ, ϵ the base of natural logarithms, and a a constant. For many purposes this system of equalized accuracy is advantageous.

* A. Campbell, British Patents 244,596 (1925) and 252,990 (1925).

4. Measurement of Capacitance

The bridge is primarily designed for quick and easy measurement of the capacitance of condensers, with approximate indication of their power factors at the same time. In making these measurements it is convenient to use a frequency of the order of 800 cycles per second (except for very large condensers). The range switch is turned to a suitable multiplier, and by means of the zero-setting devices an exact balance is obtained when the main pointer and the rheostat pointer are both at 0. The condenser to be tested is then connected across the terminals of P (as shown in Fig. 1), and a balance again obtained by adjusting the inductometer and the rheostat. The reading of the inductometer, multiplied by the factor indicated by the range switch, gives the capacitance directly; and the power factor can be deduced from the reading of the rheostat, as will be shown below.

The theory of the method is as follows. Let C be the capacitance of the condenser, and x a series resistance causing the power loss in it; and let the pulsatance $\omega = 2\pi f$, where f is the frequency. Also let P' and L' be the effective resistance and self-inductance of P, shunted by the condenser. Then

$$P' + L'j\omega = \frac{P(x + 1/Cj\omega)}{P + x + 1/Cj\omega}$$

$$= \frac{P(1 + xCj\omega)}{1 + (P + x)\,Cj\omega},$$

or

$$P' + L'j\omega = \frac{P(1 + xCj\omega)\,[1 - (P + x)\,Cj\omega]}{1 + (P + x)^2 C^2\omega^2}.$$

By separating the real and imaginary terms we obtain

$$P - P' = \frac{P^2 (P + x)\,C^2\omega^2}{1 + (P + x)^2 C^2\omega^2} \qquad \text{......(1)},$$

and

$$L' = \frac{-P^2 C}{1 + (P + x)^2 C^2\omega^2} \qquad \text{......(2)}.$$

Hence

$$\frac{R}{L\omega} = (P + x)\,C\omega \qquad \text{......(3)}$$

and

$$C = \frac{L}{P^2}\left(1 + \frac{R^2}{L^2\omega^2}\right) \qquad \text{......(4)},$$

where

$$L = -L' \text{ and } R = P - P'.$$

From these equations we have also

$$\text{Power factor} = xC\omega$$

$$= \frac{R}{L\omega} - PC\omega$$

$$= \frac{R}{L\omega}\left(1 - \frac{R}{P}\right) - \frac{L\omega}{P} \qquad \text{......(5)}.$$

Equations (4) and (5) give the capacitance and power factor with exactness from the observed quantities L' and R, if ω is known. Usually in practice all the terms in ω^2 in equations (1) and (2) are much smaller than 1, and the bridge is so designed that (for frequencies up to 800 cycles per second) these terms may generally be neglected (except for very large or very leaky condensers). Then equation (4) becomes

$$C \fallingdotseq L/P^2 \qquad \text{......(6)}.$$

Thus the capacitance C is obtained by multiplying the reading L of the inductometer by the factor $1/P^2$. As mentioned in §2, the range switch gives a series of values of P^2 from 10 up to 10^7, and hence the multipliers are 0·1 μF, 0·01μF, 1000 $\mu\mu$F, 100 $\mu\mu$F, 10 $\mu\mu$F, 1 $\mu\mu$F and 0·1 $\mu\mu$F. The total range of the instrument is thus from (say) 1 $\mu\mu$F up to 30 μF. On the two highest ranges (*i.e.* above 0·3 μF) or for very large power factors, the correction due to the ω^2 term in equation (4) is sometimes required. In order to avoid the correction for the highest ranges, the tests can be made at a lower frequency (*e.g.* 100 cycles per sec.). On the low ranges, a rather powerful source of current should be used, as the shunting method involves reduction of sensitivity. The simplicity of working, however, makes up for this disadvantage.

In many cases R/P is so small that it can be neglected in equation (5), which becomes

$$\text{Power Factor} \fallingdotseq \frac{R}{L\omega} - \frac{L\omega}{P} \qquad \ldots\ldots(7).$$

It will be noticed that the power factor comes out as the difference of two quantities often much larger than itself, and it must be kept in mind that the instrument has been designed for the easy measurement of capacitance, and not for the determination of very small power factors. On the other hand, very leaky condensers (*e.g.* with wet paper dielectric) can be directly tested.

The internal series resistance x may be found also by another method. A second test is made with a resistance z in series with the condenser C, the new readings being R_1 and L_1. Thus

$$x = \frac{RL_1 z}{R_1 L - RL_1} - P \qquad \ldots\ldots(8).$$

In general it is well to earth the junction of the proportional arms, and a terminal is provided for this purpose. The screened side of the condenser C should be connected to the point F (Fig. 1).

5. Comparison of Nearly Equal Condensers

Two nearly equal condensers can be compared with high accuracy by shunting one across P and the other across Q, with the range switch set at a low multiplier. The multiplied L reading will then give the absolute difference between their capacitances. In this way very exact matching against a standard can be done. For example, two condensers X and Y were compared against an accurate standard of 0·02 μF. Condenser X was found to be 52 $\mu\mu$F above the standard, and Y, 492 $\mu\mu$F below it. Assuming the standard to be exact, the respective capacitances would be 0·020052 μF and 0·019528 μF, the last figure being actually read in each case. Even if the standard is not known accurately, the difference between these numbers gives *very accurately* the difference between X and Y. If such extreme figures are to be accurate, the method must be used with care; otherwise important corrections may be neglected. To obtain the full accuracy the following procedure should be adopted. The two condensers C and K are first tested separately on normal shunt P_0, giving readings R_0, L_0 and r_0, l_0 respectively, and hence preliminary values C_0 and K_0. They are then tested in opposition, on higher equal shunts P and P, giving readings ρ and λ.

Let
$$p = P - P_0,$$
$$A = pC_0\omega + R_0/L_0\omega,$$
and
$$B = pK_0\omega + r_0/l_0\omega.$$

The preliminary separate tests give A and B, which will appear in the correcting terms for the comparison test.

The full formulas are

$$C - K = \frac{\lambda}{P^2} + \frac{CA^2}{1 + A^2} - \frac{KB^2}{1 + B^2} \qquad \text{......(9),}$$

and

$$\frac{\rho}{P^2\omega} = \frac{CA}{1 + A^2} - \frac{KB}{1 + B^2} \qquad \text{......(10).}$$

From these equations we obtain

$$C - K = \frac{1}{P^2}\left[\lambda(1 - AB) + \rho\frac{A + B}{\omega}\right] \qquad \text{......(11),}$$

when C and K are not greater than 0·1 μF, and the power factors are not very large, a close enough approximation is given by

$$C - K \doteqdot \frac{\lambda}{P^2}(1 + 3P^2\omega^2 C_0 K_0) \qquad \text{......(12).}$$

We have also

$$\text{Difference of Power Factors} = A - B - P\omega(C - K) \qquad \text{......(13).}$$

When the substitution method is used the corrections become more nearly negligible.

6. Measurement of Small Inductances.

The bridge is convenient for the measurement of self-inductances from 1 or 2 microhenries up to 300 μH, the effective resistance being determined at the same time. The range switch is set to short-circuit P and open-circuit Q. With a copper link across the Q terminals, the inductometer and the rheostat are both set to zero when a balance has been obtained. The link is now replaced by the coil to be tested, and a new balance obtained. Then the readings of the inductometer and rheostat for balance give the L and R of the coil. If the R is above 0·6Ω, however, the rheostat B is not sufficient, and a constant inductance rheostat or resistance box must be connected into the P arm. An auxiliary coil can be added to carry the range up to $L = 500$ μH. As the scale of the instrument is so open at the lower readings, it is very well adapted for measurements of the inductances of small radio tuning coils. The terminals are also arranged to allow the measurement of mutual inductances (coupling) down to 0·5 μH.

7. Measurement of Low Resistance

Low resistances can be measured in a similar way, 1 division on the lower range of the rheostat being 0·001 ohm. The preliminary zero settings should be made with a copper link across the Q terminals.

8. Measurement of High Resistance

A high resistance can be approximately measured by connecting it across the P terminals, with the range switch at a suitable value, and observing R, the rheostat reading required for a balance. If the unknown resistance is g, then

$$R = P - P' = P - \frac{Pg}{P + g}$$

$$= \frac{P^2}{P + g},$$

or

$$g = P^2/R - P \qquad \text{......(14).}$$

By choosing P small compared with g we have

$$g \fallingdotseq P^2/R \qquad \text{......(15).}$$

Thus the range of measurement runs from 20 ohms up to 40 or 50 megohms.

The method is a convenient one for testing grid leaks.

Example. A grid leak was tested at 800 cycles per sec., and with $P^2 = 100{,}000$. It gave $R = 0{\cdot}20\,\Omega$, showing its resistance to be 5·0 megohms. The reading of the inductometer was 4·5 μH. To deduce the capacitance, we must here use equation (4), since x is so very large. The series capacitance comes out at about 350 $\mu\mu$F, which appears considerable, but it will be found that even at radio frequencies it is still swamped by the resistance. When desired, these tests can be made with direct current, using a sensitive galvanometer in place of the telephone.

9. Testing of Highly Inductive Coils

The direct measurement of very large self-inductances (up to hundreds of henries) and the associated effective resistances is difficult, as accurate high-reading inductometers are not at present available. Some years ago Dr D. W. Dye* got over the difficulty by the ingenious device of testing the coil when shunted by a suitable non-inductive resistance. His method is probably the most accurate way of testing such coils at present known. In it, the procedure is very similar to that now described (§ 4) by the author for measurement of capacitance, but the formulas in the two cases are quite different. In Dr Dye's method the formula which gives the self-inductance involves the frequency, and it is not possible to make the method direct-reading. The present bridge is conveniently arranged for carrying out the method, the inductive coil being put across the resistance Q (Fig. 1), and the readings taken just as for a capacitance. If the coil has self-inductance l and effective resistance r, and the readings of the inductometer and the rheostat are L and R respectively, then, as Dr Dye has shown,

$$r = \frac{P^2R}{R^2 + L^2\omega^2} - P \qquad \text{......(16),}$$

and

$$l = \frac{P^2L}{R^2 + L^2\omega^2} \qquad \text{......(17).}$$

When the frequency is known, these equations enable r and l to be deduced from the observations. In the case of inductive coils with iron cores, it is usually necessary to know the terminal voltage under which the coil is tested; this is equal to $PI/2$, where I is the total current sent into the bridge.

Example. The primary and secondary coils of a small intervalve transformer were tested. The following table gives the results:

Coil tested	ω	R ohms	L μH	r ohms	l henries
Primary	5000	0·072	66·5	524	5·78
Secondary	5000	0·0287	30·7	118000	126·5

Self-inductances down to 10 mH can be measured in this way on the bridge.

10. Measurement of Frequency

The frequency of the source can be measured easily in the following way. A condenser C is connected in series with a resistance Y large enough to swamp x, the internal loss resist-

* D. W. Dye, *Experimental Wireless and Wireless Engineer*, Sept. 1924.

ance. The combination is put across the terminals of P, and the L and R for balance observed in the usual way. Then

$$R/L = (P + x + Y)\, C\omega^2,$$

or

$$\omega^2 \fallingdotseq \frac{P^2 R}{L^2 (P + x + Y)}$$

$$\fallingdotseq \frac{P^2 R}{L^2 (P + Y)},$$

or

$$\omega \fallingdotseq \frac{P}{L} \sqrt{\frac{R}{P + Y}}, \qquad \ldots\ldots(18),$$

and

$$\text{Frequency} = \omega/2\pi.$$

P and Y should be chosen so as to make R readable with accuracy. The capacitance C does not require to be known but should have a small power factor. A convenient value is 0·01 μF.

The whole apparatus is compact and self-contained, and all the measurements can be made quickly and easily. As will be seen from the examples given above, the instrument ought to prove convenient for makers and users of radio apparatus.

A TORSION ANEMOMETER. By J. P. REES,

A.R.S.M., B.Sc., D.I.C. Birmingham University Mining Dept.

[*MS. received, 20th December*, 1926.]

ABSTRACT. An account is given of a new instrument for measuring horizontal air velocities up to 3 ft. a second. This instrument has been produced for the Committee on the Control of Atmospheric Conditions in Hot and Deep Mines, particularly for use in such mines where the physiological aspect of ventilation is important. The air velocity is measured by measuring the torsion necessary to keep a vane vertical in the air current, the vane being suspended by means of the wire to which the torsion is applied.

Introduction

The Windmill type of anemometer, universally used in mines, is unreliable at low air speeds. A well-made instrument, when new, will start recording at a velocity as low as 30 ft. a minute, but some experiments made to check the calibration of an anemometer in use showed that the errors were liable to be very large with velocities as high as 100 ft. a minute, and that the instrument was not reliable until speeds of at least 150 ft. were being recorded.

An instrument of greater delicacy is therefore needed to obtain accurate information of the state of ventilation in mines. This is particularly the case when the physiological aspect of ventilation is being considered. The windmill anemometer is quite suitable for measuring the gross quantities through the main airways, for in such cases the velocities are high, but in the working places the velocity of the air is reduced by the larger cross-sectional area, and on the average is probably about 100 ft. a minute, though more information is needed on this point. The effect of ventilation on the dilution of firedamp and other gases depends on the volume of the air passing, as does also the effect of ventilation on the temperature of the air at the face, but the effect of ventilation on the cooling power of the air depends on the velocity of the air, the temperature being the same. An increase of velocity when the velocities are small has a remarkable effect on the cooling power of the air, whilst even a large increase has little effect, when the velocities are already large. Hence velocities of over 200 ft. a minute are not as a rule needed at the face, provided the volume is adequate.

It becomes then all the more urgent that there should be an accurate method of measuring these low velocities.

The instrument described has been produced for the Committee on the Control of Atmospheric Conditions in Hot and Deep Mines. It is designed to register velocities from 10 to 180 ft. per min.

Description of the Instrument

The instrument has been made by Messrs C. F. Casella & Co., Ltd., and many of the details of the design are due entirely to them.

It consists essentially of a thin rectangular aluminium vane 2·5 inches by 2·5 inches, suspended from a horizontal wire 7·5 inches long. The wire is 0·006 inch full diameter, of plated, hardened and tempered steel. The vane is centrally placed, so that there is 2·5 inches of free wire on either side, the central 2·5 inches being soldered to the vane. The ends of the wire are soldered into small brass nipples, which are fixed into a frame. One nipple slides into the frame, so that the wire can be pulled tight, and the nipple fixed by a grub screw. The other has a collar on it, so that it can be pulled tight against the frame.

The vane is thus hung vertically from a horizontal wire. It swings out of the vertical, when a current of air impinges on it. It twists the wire as it swings, and the twisting tends to limit the amount of displacement. The weight of the vane also tends to bring the vane back to the vertical. A balance is thus established, between the couple due to the weight of the vane plus the torsion of the wire, and the couple due to the pressure of the air. By measuring the amount of the deflection it would be possible to determine the velocity of the air. By this method the maximum useful deflection is about 30°. The range of velocities that can be observed is therefore limited. To get over this difficulty the vane is kept vertical, when a current of air impinges on it, by twisting the wire. The velocity of the air is obtained by measuring the twist, or torsion necessary to bring the vane back to vertical. Only one end of the supporting wire is twisted. When the vane is brought back to normal, the other end is also in its normal condition, and has no twisting effect on the vane. Further advantages of bringing the vane always to a vertical position are, that the effect of the weight of the vane is obviated and the pressure is always normal to the face.

When measuring very low velocities, say 10 or 20 feet a minute, it is very important that the observer should be as far as is practicable from the vane, in order that the deflections in the air current due to his bulk shall not affect the reading. For the same reason the vane must stand out clear of the tripod and any other part of the instrument. The makers have therefore arranged that the torsion shall be applied at a point two feet behind the vane, by means of a light shaft and bevel gearing. The torsion rod is enclosed in a tube and the tube is supported on a tripod.

A levelling bubble is fixed on the tube and parallel to it, so that the vane in its frame can be accurately levelled, in a plane normal to the vane, by means of levelling screws. A level is also provided on the frame, so that the instrument can be levelled in the plane of the vane. In this direction, precise levelling is not important, and it can be done with sufficient accuracy by adjusting the tripod legs. Underneath the vane is a small container for oil, and an extension from the vane itself, dipping into the oil, acts as a baffle and slows down its movements. The container is closed by two sliding lids, which close on the baffle and hold the vane still when it is not in use.

A small telescope is used to enable the position of the vane to be observed. A circular plane mirror is fixed to the vane, and the telescope is directed on to this mirror, in which is seen the reflection of two datum lines alongside the telescope. In the normal position, the reflection of these datum lines, as seen in the telescope, lies equally on either side of the cross wire in the telescope. When the instrument is in a current of air, the vane is blown out of its normal position. It is brought back by turning a knob at the end of the torsion rod,

until the reflection of the datum lines again lie equally on either side of the wire as seen in the telescope. The angle through which the torsion rod is turned is measured by a pointer and scale. As the motion is geared down by the bevel gearing, the actual torsion of the wire is only half the number of degrees registered on the scale. The photograph shows the instrument as seen from behind.

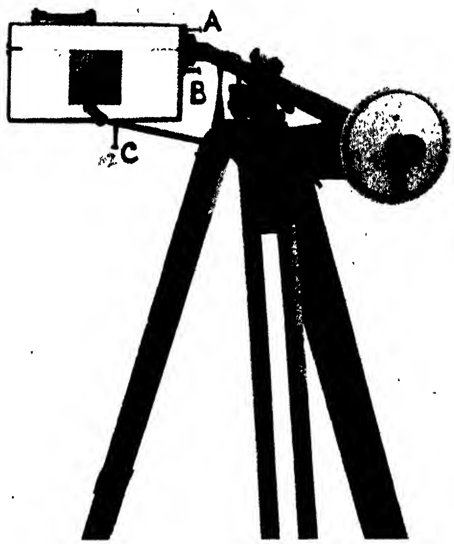


Fig. 1. The Torsion Anemometer

The Instrument in Use

The instrument dismantles into three parts for transport, (1) a small box holding the telescope and the vane in its frame, (2) the torsion tube, and (3) the tripod legs. The torsion tube, the ends of which are protected by canvas covers, may be strapped to the tripod legs, if convenient.

When the tripod is set up, the torsion rod is fixed to it, and the vane fixed to the rod by three screws shown at *A*, *B*, *C* in the photograph. The telescope is easily fixed by two small wing nuts, also shown. The vane is placed normal to the direction of the air current and roughly levelled by adjusting the tripod. It is then accurately levelled in a direction at right angles to the plane of the vane, by means of the level on the torsion rod and the levelling screws underneath. This levelling must be done as accurately as possible. The position of the pointer, when the vane is normal in still air, is of course known, and by sighting through the telescope and turning the knob, torsion can be applied to the vane to bring it back to normal. The velocity of the air can then be obtained either from a calibration chart or directly from the instrument.

Except in slight air currents, the vane will always oscillate, in spite of the oil and baffle. When that is the case torsion must be so applied that the datum lines seen in the mirror swing equally to each side of the crosswire.

It is obvious that a disadvantage of the instrument is that it would be a long and somewhat difficult process to make a traverse of any particular cross-section of an airway. Owing to the instrument being supported on tripod legs and having to be carefully levelled, it is really only suitable for taking readings at one or two points in an airway. However, in many cases, such readings may be as valuable as a complete traverse.

SOME NOTES ON PAINTS FOR COMPASS BOWLS AND DISCS.

Investigation by H. L. SMITH, B.Sc., F.I.C. Research Report by the British Scientific Instrument Research Association.

CONSIDERABLE trouble has been experienced with paints for compass bowls and discs.

(1) The paint has become discoloured either generally or in spots.

(2) The alcohol used in filling the compass bowl has become discoloured.

(3) The paint has a tendency to flake or peel off.

The bowl is filled with alcohol, in some cases with about 60 over proof alcohol, *i.e.* about 91 per cent. alcohol by volume, in other cases the alcohol is rather more dilute. The consideration of the effect of the alcohol on the paint is of importance, not only on account of possible solvent action on the medium of the paint, but also on account of small quantities of substances in the alcohol which may exert a reducing action on the pigment of the paint.

A further source of trouble is the rubber ring used to seal the compass bowl. It has been proved by experiment that such rings of vulcanised rubber give up small quantities of sulphur compounds to the alcohol. Although the bulk of rubber compared to the alcohol is small, the amount of sulphur extracted by the alcohol is sufficient to cause tarnishing on a piece of silver, when the alcohol is removed from a compass and warmed with a piece of silver immersed in it. The sulphur compound in the alcohol gives no reaction with lead acetate.

Some paints which have been used or suggested for use in compasses have been examined. They fall into three distinct classes:

(1) Paints made with an oil medium.

(2) Paints made with an aqueous medium, *e.g.* a solution of gum arabic.

(3) Paints made with solutions of nitrocellulose.

Class (1). Three specimens were examined.

A. Contained as pigment a mixture of antimony oxide and zinc oxide. The medium was of the ordinary paint or varnish character, containing oil and some resinous substance. It was thinned with petroleum and a little amyl alcohol. From the dried film of this paint the alcohol dissolved out some of the resin and became discoloured.

B. The pigment in this paint was a mixture of zinc sulphide and magnesium oxide or carbonate, with iron as an impurity. This paint has been found to become discoloured on exposure to light.

C. This paint could only be examined as a dried film on a compass disc. The pigment was white lead. There was evidence of the presence of some resin. The paint was discoloured in spots, but not badly. The alcohol in the compass was not discoloured. On the removal of the disc from the alcohol the paint cracked and peeled off the mica disc.

Class (2). One sample examined.

The pigment in this paint was white lead. The medium was an aqueous solution of gum arabic with some glycerine and a small quantity of some protein substance. The protein substance was not identified.

The objection to this paint was that, except in a very dry atmosphere, it did not dry, and on a moist day it became sticky. Experiment showed that the glycerine did not dissolve out immediately in the alcohol. After a few weeks, however, there is a tendency for the film to crack if the alcohol is of full strength. Some experimental mixtures showed that the addition

of gelatine does not improve the paint, but that the addition of a little casein, dissolved by means of calcium hydroxide, made a paint closely approximating to the sample.

Casein	2	parts by weight.
Calcium hydroxide	0·5	,, ,,
Mucilage of gum arabic	60	,, ,,
Water	40	,, ,,
White lead	65	,, ,,
Glycerine	5	,, ,,

The mucilage of gum arabic is made by digesting 100 grams of gum arabic in 150 c.c. of cold water.

Class 3. Three samples examined.

Two of these paints had antimony oxide as the pigment, the third had zinc oxide as the pigment. The medium in each was nitro-cellulose (pyroxylin or collodion cotton) dissolved in amyl acetate. One sample contained in addition a considerable quantity of camphor, which dissolves readily in alcohol.

Antimony oxide is a much denser pigment than zinc oxide, which has but little covering power. The zinc oxide paint adhered much better to the mica disc than the antimony oxide paints, but the colour was poor. Analysis did not reveal any reason for this property of adhering better to the mica.

A collodion paint with camphor forms a better film and adheres better to the mica than one without camphor, but as the camphor is removed by the alcohol the film tends to curl and leave the mica.

It was found necessary to clean and dry the mica very carefully to ensure a collodion paint sticking well. Benzene followed by alcohol was found to be very useful.

Experimental Paints

As alcohol has always a tendency to soften oil paints and to dissolve some of their constituents if the film is at all new, attention was more particularly paid to paints made with aqueous media, and to paints made with solutions of nitrocellulose.

One oil paint may be worth mentioning. It was made with "Litho middle varnish," a specially thickened pale linseed oil made for use by lithographers.

Litho middle varnish	20 grm.
White lead	50 ,,
White spirit (turpentine substitute)	20 c.c.

By itself this paint takes too long to dry. A small quantity of a patent drier, composed of manganese and lead salts of resin acids, was added, and the drying was accelerated. A drier composed of the lead salts of the acids of Chinese wood oil was found still better, 5 grams being added to the quantity of paint in the formula. The drying can be further accelerated by warming to a temperature of 50° C.; at this temperature the paint does not darken. This paint withstood the action of alcohol over a period of three months. No change in the paint nor discoloration of the alcohol was observed.

Paints made with Aqueous Media

One advantage of these paints is that substances can be chosen on which alcohol has little or no action. On the other hand, the dehydrating effect of strong alcohol may make them brittle and liable to flake off.

Casein appeared a promising substance, and a number of experiments were carried out with it. Casein is insoluble in water, but will dissolve in solutions of the alkalies and in

presence of lime (calcium hydroxide). The alkalies cannot be used, even in small quantity, as alcohol, unless very pure, becomes discoloured in their presence. Oxides such as zinc oxide will not dissolve casein in presence of water. There is a slow action between zinc oxide and casein; a compound is formed which is not soluble and is not readily dispersed when the paint is shaken or stirred.

In general, casein paints made with lime do not keep well in the mixed condition; they tend to cake and, if employed, it would appear necessary to mix them with the water as required for use. The addition of a little mucilage of gum arabic prevents the formation of a hard deposit to some extent, but not for long.

A paint made according to the following formula gives a good white film, but it cannot be kept in the mixed condition for more than a day or two.

Casein	5 grm.
Calcium hydroxide	1 „
Zinc oxide	35 „
Mucilage of gum arabic	20 „
Water	100 c.c.

More concentrated mixtures form stiff pastes after a short time. This paint appears to be very stable in alcohol.

A white pigment of less reactive properties than zinc oxide would be preferable, and might enable casein paints to be kept in the mixed state. Pigments which form coloured sulphides are not safe to use on account of the sulphur in the casein. (See Appendix.) Titan white, which is essentially titanium dioxide, appeared a promising pigment. It was found, however, not to be stable in a casein medium; it rapidly became grey in colour.

Nitrocellulose or Collodion Cotton Paints

This class of paints appears to have been used by some manufacturers of compasses both for the bowls and also for the discs, but trouble has been experienced in the formation of discoloured patches or in a general loss of whiteness. A good example of this class of paints, which was examined, appears to be composed of a solution of nitrocellulose (collodion cotton) in amyl acetate, the pigment being antimony white, which is essentially antimony trioxide.

In making up a satisfactory paint of this class attention must be paid to the character of the pigment. Considerable difficulty has been experienced in obtaining an antimony white which will remain stable in colour, not only when painted out, but even in the mixed paint in the bottle. Under both conditions some specimens of the pigment rapidly became brownish in colour. This discoloration does not appear to be due to traces of impurities such as iron or other oxides of antimony. The only stable specimen of antimony white, which it has been possible to obtain, contained appreciable traces of iron and was not completely soluble in tartaric acid solution. Antimony trioxide itself is completely soluble in a solution of tartaric acid. Other specimens which were purer and dissolved completely in a solution of tartaric acid were not stable as regards colour.

A paint made up as follows, using the stable specimen of antimony white referred to above, has given satisfaction:

Antimony white (Britannox)	150 grm.
Pyroxylin (collodion cotton)	10 „
Amyl acetate	180 c.c.

The pyroxylin is dissolved in the amyl acetate and carefully decanted or filtered from any undissolved particles. The pigment is then ground into the solution.

Titan white was tried as a substitute for the antimony white; its specific gravity is less, so a smaller weight is required, it grinds up well with the solution of pyroxylin and the resulting paint appeared quite satisfactory at first. The colour, however, is not permanent, and when painted out it soon becomes discoloured. Even with the most carefully made antimony white paint spots of a brownish colour are found to develop sometimes. This would appear to be due to local differences in the character of the brass, causing greater chemical activity. It is, perhaps, at these active areas of the brass that the sulphur compounds, extracted by the alcohol from the rubber sealing ring, can react and so cause discoloration due to the formation of sulphides.

The only satisfactory method of stopping this local discoloration appears to be to use an impervious undercoating, such as a stoved enamel, before using the antimony paint.

APPENDIX

Note on the Action of White Lead on Casein in the Presence of Lime

It is well-known that alkaline solutions of lead react readily with proteins which contain sulphur, such as casein, with the formation of lead sulphide. Some experiments have been carried out with a view to determining the stability of the gum arabic paint referred to in this report.

The following were kept at a temperature of about 120° C. to 130° C.:

(1) The commercial gum arabic paint referred to above.
(2) The gum arabic paint made up according to the formula given.
(3) About equal weights of casein, white lead and calcium hydroxide with water.
(4) The same as (3), with the addition of a few drops of 10 per cent. solution of caustic soda.

After six hours, only No. 4 showed any darkening. After another six hours' heating, No. 3 showed a slight darkening. Nos. 1 and 2 showed no darkening. It may be concluded that casein in the quantity suggested in the formula may be used with white lead with safety, but that it would not be wise to use white lead in a paint the liquid medium of which consisted largely of a strong solution of casein.

The mixture No. 3 contains much more casein in proportion to the lead than would occur in a paint, and is a very stringent test, yet the darkening which occurred finally was very slight.

THE VALVE FILAMENT AT CONSTANT VOLTAGE.

By E. H. W. BANNER, M.Sc., A.M.I.E.E., A.Inst.P.

[*MS. received, 2nd December*, 1926.]

SUMMARY. When the filament of a thermionic valve emits and a thermionic current flows from the filament to the anode and through an external circuit back to the filament, the filament current is necessarily different at all points along the filament.

An ammeter in each filament lead and a voltmeter across them will all read differently when the valve emits, the actual deviations depending on the electronic emission and the circuit used. The only exceptions are the case of a filament connected directly to a source of P.D. with no intermediate rheostat, when the voltage will be maintained constant by the supply, but the currents will vary in any case. The other exception is that of the valve with the separately heated cathode, the potential of which is uniform.

The variations of the reading of the filament voltmeter and ammeters have been investigated experimentally, and a circuit has been devised in which there is no change of reading of the voltmeter or either ammeter when the anode current is switched on and off.

The current read is the filament battery current, and with this circuit tests may be repeated on valves with the certainty of the filament conditions being constant for different tests.

An investigation was also made of the validity of the practice of readjusting the filament voltage after switching on the anode potential, and it was found that this practice is not correct as regards maintaining the filament under constant conditions, except for those valves intended to be run without a rheostat.

All tests were made with valves used as diodes, as in this case the emission is usually greater than the anode current when the valve is used as a triode.

For standard tests on valves used as triodes the precautions necessary to maintain constant filament conditions are of less importance.

For standard valve tests the circuit devised should be adhered to, and the practical means of ensuring constant conditions are indicated.

The method of reducing the asymmetry of the temperature gradient of large valves used as rectifiers is of some interest here, and the conditions have been calculated.

The experimental work necessary shows how fine precision measurements may be made with commercial instruments, as numerous checks are possible, most of which show up the accuracy of the majority of the readings, which in most cases involved a change of less than one scale division.

Finally, a valve was tested with its filament supplied with A.C., and various circuits tried. It was found immaterial to which point of the filament circuit the anode return was connected, on account of the symmetry of the temperature gradient, at any rate at 50 ~ and above.

SECTION I

THE present paper describes experimental work done as a continuation to that done at the University of Birmingham in 1924, and published in the *Proceedings of the Institute of Radio Engineers**.

After the above paper was written it was pointed out that tests on more valves—two only were tested previously—and the alteration of filament voltage as well as current would be a useful extension, and so tests on eight valves, of different filament sizes, were used.

The work was inspired by a paper by Stead†, and the primary object was an experimental investigation of the term "constant filament current" or voltage, for standard tests.

In this section observations were made of the filament voltmeter and ammeters with the return lead connecting to various points on the filament circuit (Fig. 1), with the valve not emitting and emitting.

The two main sets of conditions were:

1. (*a*) Filament battery voltage not much in excess of filament voltage.
   (*b*) Filament battery voltage greatly in excess of filament voltage.
2. (*a*) Filament rheostat in negative lead.
   (*b*) Rheostat in positive.

The sets of conditions give readings shown as:

Series A.	6 volt battery,	rheostat in	negative.
,, B.	,,	,,	positive.
,, C.	24 ,,	,,	negative.

* "Maintaining a Constant Reading on an Ammeter in the Filament Battery Circuit of a Thermionin Triode." *Proc. I.R.E.* **14**, 325.

† "The Effect of Electron Emission on the Temperature of the Filament and Anode of a Thermionic Valve." *J.I.E.E.* **59**, 427.

Test Results

Series A. 6 *V. battery. Rheostat in negative.*

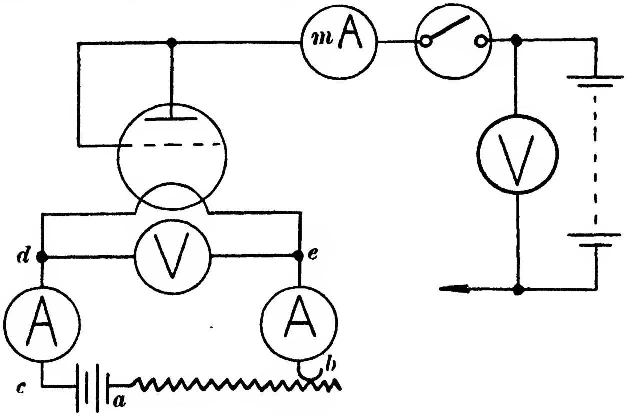


Fig. 1

Test 1. *Return lead to battery negative.* (Fig. 1 *a*.)

Valve	E_f	$I_f +$	$I_f -$	E_a	I_e	+ Down	− Up	Change
LS5	4·50	·776	·776	—	—	—	—	—
	4·45	·752	·806	50	·0545	·024	·030	·054
	4·42	·740	·826	100	·0873	·036	·050	·086
R5V	5·00	·670	·670	—	—	—	—	—
	4·97	·666	·676	50	·00945	·004	·006	·010
	4·97	·665	·678	100	·0101	·005	·008	·013
R	4·00	·653	·653	—	—	—	—	—
	3·98	·650	·655	50	·0079	·003	·002	·005
	3·98	·649	·655	100	·0083	·004	·002	·006
DER	1·80	·400	·400	—	—	—	—	—
	1·75	·391	·404	50	·0132	·009	·004	·013
	1·75	·391	·404	100	·0144	·009	·004	·013
DE5	5·50	·245	·245	—	—	—	—	—
	5·53	·231	·274	50	·0420	·014	·029	·043
	5·42	·230	·278	100	·0458	·015	·033	·048
DE8	5·60	·115	·115	—	—	—	—	—
	5·54	·109	·129	50	·0204	·006	·014	·020
	5·54	·109	·130	100	·0208	·006	·015	·021
DE3	2·80	·061	·061	—	—	—	—	—
	2·70	·059	·064	50	·0051	·002	·003	·005
	2·69	·059	·064	100	·0055	·002	·003	·005
Diode	15·00	·060	·060	—	—	—	—	—
	14·83	·056	·070	50	·0155	·004	·010	·014
	14·80	·055	·070	100	·0173	·005	·010	·015

For this valve the battery voltage was 16 volts.

The columns $I_f +$ and $I_f -$ are the currents, measured by ammeters, in the positive and negative leads respectively.

+ Down and − Up mean the decrease of reading of the positive ammeter and the increase of the negative, respectively. The last column is the sum of the changes recorded in the two previous columns.

Test 2. *Return lead to filament negative.* (Fig. 1 *b*.)

LS5 Valve.

E_f	$I_f +$	$I_f -$	E_a	I_e	+Down	−Up	Change
4·50	·777	·777	—	—	—	—	—
4·54	·762	·818	50	·058	·013	·041	·054
4·56	·752	·825	100	·098	·023	·048	·071

Test 3. *Return lead to positive.* (Fig. 1 *c.*)

E_f	I_f+	I_f-	E_a	I_e	+Down	−Up	Change
4·50	·781	·781	—	—	—	—	—
4·44	·756	·819	50	·0635	·025	·038	·063
4·40	·742	·836	100	·0930	·039	·055	·094

Test 4. *Return lead to positive above ammeter.* (Fig. 1 *d.*)

E_f	I_f+	I_f-	E_a	I_e	+Up	−Up	Change
4·50	·780	·780	—	—	—	—	—
4·44	·816	·813	50	·0625	·036	·033	·069
4·40	·832	·830	100	·0890	·052	·050	·102

Test 5. *Return lead to negative above ammeter.* (Fig. 1 *e.*)

E_f	I_f+	I_f-	E_a	I_e	+Down	−Down	Change
4·50	·780	·780	—	—	—	—	—
4·54	·765	·764	50	·057	·015	·016	·031
4·56	·754	·754	100	·101	·026	·026	·052

Series B. 6 *V. battery. Rheostat in positive.*

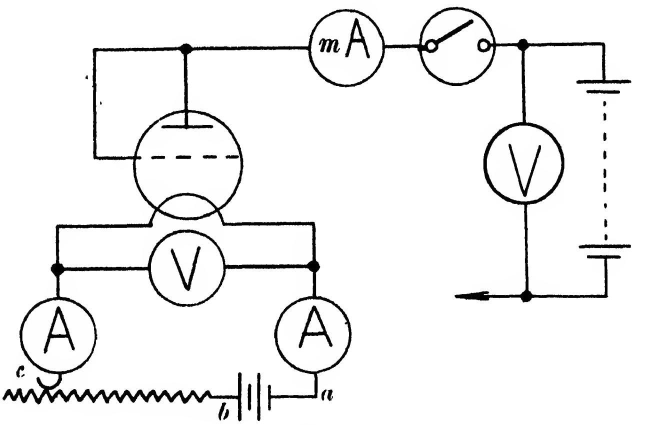


Fig. 2

Test 6. *Return lead to negative.* (Fig. 2 *a.*)

E_f	I_f+	I_f-	E_a	I_a	+Down	−Up	Change
4·50	·784	·784	—	—	—	—	—
4·53	·773	·822	50	·057	·011	·038	·049
4·54	·762	·858	100	·104	·022	·074	·096

Test 7. *Return lead to battery positive.* (Fig. 2 *b.*)

E_f	I_f+	I_f-	E_a	I_a	+Down	−Up	Change
4·50	·778	·778	—	—	—	—	—
4·52	·765	824	50	·0662	·013	·046	·059
4·54	·755	·850	100	·1010	·023	·072	·095

Test 8. *Return lead to filament positive.* (Fig. 2 *c.*)

E_f	I_f+	I_f-	E_a	I_a	+Down	−Up	Change
4·50	·780	·780	—	—	—	—	—
4·43	·753	·815	50	·062	·027	·035	·062
4·40	·743	·831	100	·088	·037	·051	·088

Series C. Tests 9–13. Readings are not tabulated but the results are stated and discussed.

Discussion of Results

The tests in Series A were made with a 6 volt battery for a 4·5 volt filament, in the case of the LS5 valve. In all cases, except those where the return lead was connected between the filament and the ammeters, the reading on the positive ammeter decreased, and the negative increased; further, the decrease of the negative ammeter reading was greater than the increase on the other ammeter. In the two exceptions to this generalisation on the readings of Test 1, the R and the DER valves have the positive ammeter increase greater, but as the difference between battery voltage and filament voltage is greater than for most of the other valves, the conditions approach those of Series C, where a 24 volt battery was used.

It may be stated, then, that for battery voltages not greatly in excess of the filament voltage the increase of current due to emission is greater than the decrease at the other end. This is true for all anode voltages.

Series C, using a 24 volt battery, gives different results; as before, the negative ammeter reading increases with emission, but now only when the return lead is to the filament negative is the negative increase greater than the positive decrease. With the return to the positive or to the battery negative the reverse holds.

The general inference is then that when the battery voltage greatly exceeds the filament voltage the negative ammeter increase is less instead of greater than the decrease on the positive ammeter. For the exceptional case (Test 10), the rheostat being in the negative lead and the return to the most negative part of the filament circuit, the effective potential difference between the filament itself and the anode is less than for the other cases. The circuit then approaches those of Series A, where the battery voltage is not much greater than the filament voltage, and the same result is found. Professor Appleton states* that the increase at the negative end is 7 per cent. of the normal and the decrease at the positive end 3 per cent. This agrees with the results here, in general.

In each case, with the return lead above the ammeter, the two ammeter readings are the same—within the limits of experimental error—as an inspection of the figures will show, since the filament battery has no branch circuit, the two ammeters being in effect in series.

The next point to note is that with the exception of cases with the return lead to the filament above either of the ammeters, the sum of the changes of the two ammeters is equal to I_e, the emission current, again within the limits of experimental error.

This no longer holds when the return lead is connected above either of the ammeters, as the sum of the changes is twice that of one of them, and the two ammeter changes are not equal, with the return to any point below the ammeters, in any of the tests performed, but it is possible that a filament battery voltage could be found that would produce equal changes of current on both ammeters.

Considering Series A and B, the difference due to the rheostat being either negative or positive is seen. Again the sum of the changes equals the emission, with a positive rheostat, and also the increase of the negative ammeter reading predominates. From the ammeter readings alone, therefore, it may be stated than in general the rheostat may be either positive or negative, the change of ammeter readings being due solely to the point of connection of the return lead.

Filament Voltage Change

The alteration of voltmeter reading can be summed up more simply than can the ammeter readings, and Fig. 3 shows the general result.

With the return lead to the filament positive E_f decreases, with the return lead to the

* "On the form of free triode vibrations." *Phil. Mag.* **42** (Aug. 1921) 201.

filament negative E_f increases, and with the return to the intermediate point the effect is the same as if it were connected to the other end of the battery, and the reverse from that at the other end of the rheostat.

Most of the valves tested were saturated at $E_a = 100\,V$, but the LS5 is not saturated at this voltage, although the I_e/E_a curve is no longer on the straight part.

Test 1, with the figures for all the valves used, enables a comparison to be made for valves which were saturated under the conditions of the test, and those that were not.

The LS5 and the special Diode were not saturated at $E_a = 50\,V$, but they were both on the top bend at $E_a = 100\,V$.

The ratio of the negative increase to the positive decrease is fairly constant for all the valves at $E_a = 50$ and $100\,V$ except the R and the DER, which, as previously stated, had a greater voltage drop in the rheostat.

Comparison of Series A and C, the test conditions of which are similar except for a 6 volt and a 24 volt battery respectively, show that the alteration of filament voltage due to emission is in the same direction in each case, but it is much more marked in the case of the 24 volt battery.

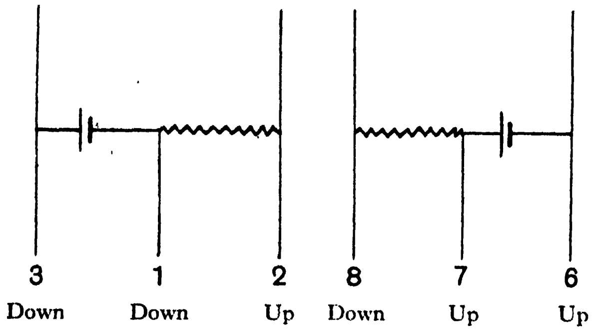


Fig. 3

This shows that with a high resistance filament rheostat the conditions are not the same as with a small rheostat, and, of course, with no rheostat the filament voltage is maintained independent of emission, except to the small extent due to the alteration of current affecting the supply voltage.

SECTION II

The previous section is really preliminary to the primary object of the research, which was to find a circuit with the return lead connected to the filament circuit so that the filament voltmeter reading would not be altered when the anode battery was switched on.

Previously work had been done to find a circuit giving no change of filament amperes, and as filaments are preferably run at constant voltage instead of constant current the original circuit was examined for validity in the new condition.

Section I showed that with the return lead to one end of the filament the voltmeter reading increased, and to the other it decreased. To obtain intermediate points a potential divider was placed across the filament, with the return lead to a tapping on this. Readings were taken with the return lead to ·1, ·2, etc. of the total resistance from the negative end to the positive. The potential divider had three values for each test on each valve, the total resistance being 10,000, 1000 and 100 Ω.

In order to obtain a constant and accurate resistance two standard resistance boxes were used in series, with the return lead to their junction. The total resistance was maintained constant for each test by varying both resistances. Tests with a slide-wire rheostat

were found to be valueless, on account of lack of uniformity of resistance with position of slider, for accurate work.

Fig. 4 shows the circuit used.

All test results are not given here, but they all follow the same cycle. Fig. 5 shows graphically the results of Test 15, but with different scales could be applied to other tests in this series.

The main observation is that, with the return connected to the filament circuit at the point which gave no change of ammeter readings, the voltmeter reading was also maintained constant. This is the main experimental fact which was at the outset to be explored.

The voltmeter reading is quite definite, and this circuit thus provides a standard for accurate tests, when it is essential to maintain a constant filament voltage, or, in general, constant filament conditions, externally to the valve.

The tests also showed that the total resistance of the potential divider does not affect the voltmeter readings. The alteration of resistance is shown in the columns of I_{f0} (filament battery current) and I_e, in the former by the increased readings with a low resistance, in

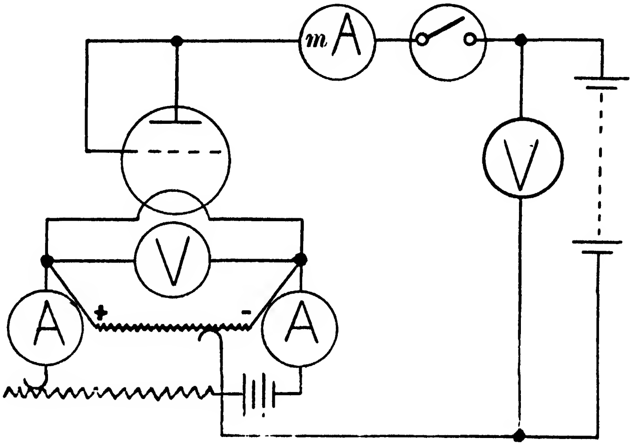


Fig. 4

the latter by a smaller emission current with a high resistance, due to part of the ohmic resistance being virtually in series with the anode battery, thus reducing the effective voltage.

It is suggested that a compromise should be made, and the potential divider be of about 1000 Ω total resistance, with valves having filament voltage of a few volts, but this value is not necessarily the best for all cases.

A summary is given of the ratios (*i.e.* position of slider from negative end of filament) for the other valves tested.

LS5 ...	·3	DER	·2 or ·3
Diode ...	·3	DE5	·3
DE8, LF ...	·3	DE3	·2
R5V ...	·3	Mullard ORA ...	·17 } 1922 tests.
R ...	·3	Dutch Valve ...	·17 } 1922 tests.

Attempts at solutions of this network indicate that the ratio should be ·5, or that the return lead should be to the centre of the network. Tests showed that the return to the centre of the filament is correct, but the discrepancy between the two cases is believed to be due to some end-effects of the filament, and that an infinitely long filament, or one having no cooling at the ends, would require a network as described, with a ratio of ·5.

In the Appendix a table is given of the characteristics of the valves, to endeavour to correlate the various ratios with the valve dimensions.

The two readings of ·17 are certainly not in error, as the measurements were made to considerable accuracy by a method devised at the time of the previous work*.

An inspection of Fig. 4 shows that the rheostat may be equally well in either battery lead, as may also the ammeter. The effect of a 24 volt battery instead of a 6 volt, and of anode voltages from 0 to 100 volts were also tried, with no variation of constancy of readings at the points stated.

It is significant to note that as the changes of E_f and I_{fb} are in opposite directions as the slider is moved from one end to the other, it is more important to have the return lead at the correct point than if both varied in the same direction. With the return lead at the correct point for no permanent change of instrument readings a transient occurs on both instruments on switching the anode battery on and off. The instruments were carefully observed whilst switching-on and it was seen that the voltmeter reading increased very slightly and the ammeter reading decreased, then both quickly resumed their original readings. The time of the transient was of the order of a second, and the changes were very small. This indicates that on switching-on the filament resistance increases very slightly, but quickly regains its original resistance when connected as in Fig. 4. Switching-off shows the reverse phenomena. Connecting otherwise shows a permanent change of resistance.

A further observed fact was that when the valves were emitting, the total light emitted from the bulb decreased. The change of brilliancy was quite marked in the case of those bulbs which were partly obscured by a getter. This appears to show a fall of average temperature.

(To be continued)

SIMPLE APPARATUS FOR DEMONSTRATING DIRECTLY THE ACCELERATION OF GRAVITY.

By D. A. WELLS, Instructor of Physics, University of Cincinnati.

ABSTRACT. The paper describes a simple apparatus by means of which the acceleration of gravity can be easily demonstrated. Distances travelled by a falling body during successive time units can be projected directly on to a screen. The apparatus is essentially an arrangement for projecting light from a falling drop of water, the light being interrupted at a constant frequency by revolving sectors.

There are a number of pieces of apparatus for roughly determining the value of the acceleration of gravity, but no device has been described that is especially suitable for direct lecture demonstration. Most apparatus now used is too complicated and indirect for elementary students to get a good idea of what is taking place. The apparatus herein described fulfils the above requirements very well indeed.

Referring to the figure, A is a strong source of light, such as an arc. R is a rotating shutter consisting of two or more sectors cut from a disc, as shown in the lower drawing. D is a reservoir from the bottom of which leads a small capillary tube with a bore of about ½ mm. With the reservoir partially full of water a steady flow of drops issues from the capillary tube.

L_1 is a positive lens so placed as to form a real image of the shutter sectors in the plane of the water drops. L_2 is a positive lens which forms on the screen S_2 a real image of the

* "Reading a Very Small Change of Current." *Wireless World* (13th January, 1926) 41.

light refracted through the drops. S_1 is an opaque screen to prevent any light except that refracted by the drops reaching S_2.

The operation of the apparatus is as follows. With R removed, each drop from D forms a continuous light streak on S_2. With R in place and rotating at a constant speed of say 1500 R.P.M., the streak on the screen is cut up into equal time units. Therefore the length of any one segment is proportional to the distance travelled by the drop during the unit of time. The appearance on the screen is as shown, the length of segments being short as the drop starts and increasingly longer as the time of fall increases. By changing the speed of R, the time unit and thus the length of segments on S_2 may be varied as desired. By using an erecting lens in conjunction with L_2, the image on the screen may be reversed, but this offers no special advantage and has the disadvantage of reducing the light.

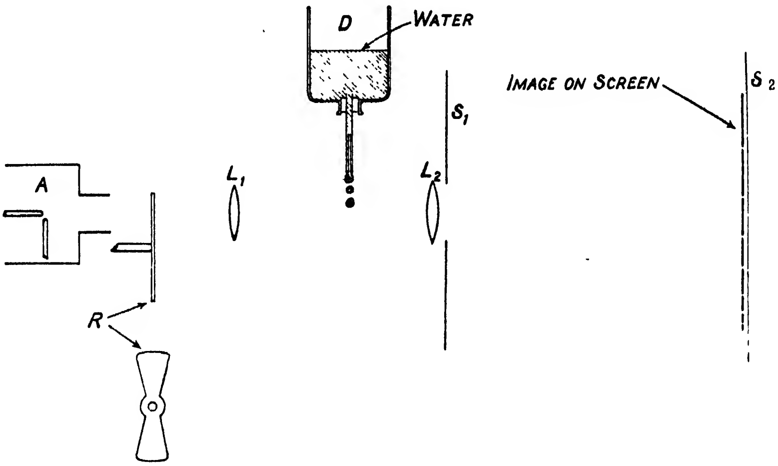


Diagram of Apparatus

The apparatus is very easy to set up and sufficient light is refracted through the drops so that S_2 may be a large screen. In order that no light except that refracted by the drops shall reach the screen, A, R, and L_1 should be arranged on the table at a slight inclination to D, L_2 and S_2, and not in line, as the diagram necessarily shows. To get good spacing between the segments of light on S_2 the sectors of R should be about two inches wide. If lenses L_1 and L_2 have a diameter of $3\frac{1}{2}$ inches they work very satisfactorily.

With a sufficiently steady flow of drops, and with R and the time of fall of drops properly synchronized, it should be possible to make fairly accurate determinations of g. However, for demonstration purposes there is no necessity for accurately synchronizing R and the drops.

NEW INSTRUMENTS

GALVANOMETERS AND CO_2 RECORDERS

The Leeds and Northrup Company of Philadelphia has just issued two new catalogues; No. 20 on Galvanometers, and No. 781 on electrical CO_2 meters. The former contains particulars of the various types of moving coil and moving needle reflecting and pointer galvanometers, astatic dynamometers and vibration galvanometers, and scale stands. A feature of the moving coil galvanometers is a tangent screw head for adjusting the zero,

and the use of a plane mirror with lens holder instead of a concave mirror. The following are the sensitivities for three of the instruments.

Resistance ohms		Period	Sensitivity	Figure of
Coil	Damping	sec.	*m/m* at 1 metre	merit
800	100,000	40	100,000 per microampere	425
12	25	7·5	10 per microvolt	—
700	35,000	27	3300 per microcoulomb	—

The moving needle galvanometer is of the Coblentz type, primarily designed for radiation measurements with thermopiles. It has four coils, which can be combined in series or parallel, and which are encased in iron, and the instrument is enclosed in a quadruple cylinder magnetic shield. A 40 ohm instrument of this type with 5 sec. period gives 5000 mm. deflection at 1 metre per microampere, or 125 mm. per microvolt, with corresponding values for the series-parallel and parallel combination of the coils, implying a figure of merit of about 4500. The vibration galvanometer is of the moving coil type, with screw adjustments for varying both the length and tension of the suspension for tuning, the range of tuning being normally 50 to 80 ~. Two forms are made, one giving 40 mm. per microampere and the other ·5 mm. per microvolt at 1 metre on 60 ~ supply, and the sensitivity to the third harmonic is only about one 2500th of that for the fundamental.

Two forms of reflecting astatic dynamometers of the Rowland type are listed, the more sensitive form having four fixed coils, as in the Kelvin galvanometers, and oil damping. A thin metal lining is provided to give electrostatic shielding, but far enough from the coils to avoid eddy current errors. It will give a deflection of 1 mm. at 1 metre for 5 microwatts; and the less sensitive form, with two fixed coils, gives the same deflection for 50 microwatts. A high sensitivity A.C. galvanometer, apparently on the Sumpner principle, is also included. With a 12 w. coil and 14 sec. period it gives 200 mm. at 1 metre for one microampere in the moving coil. Various forms of pointer and recording galvanometers are catalogued.

The CO_2 recorders are of the hot wire type, having two heated platinum wires with ratio resistances, forming a bridge through which a constant current is passed. Both the wires are in closed chambers, one of which contains dry air, and the other is connected to the flue pipe in such a manner that the flow of the gases through it is caused simply by the convection due to the heated wire and is unaffected by the rate of flow in the flue. The percentage of CO_2 is read on a pointer galvanometer or recorded on one of the firm's recording galvanometers. A double record of percentage CO_2 and flue gas temperature can be obtained, and multiple records from different flues.

RESISTANCE BOXES.

FROM the *Association des Ouvriers en Instruments de Précision* of 8 to 14 Rue Charles-Fourier, Paris XIII, we have received a catalogue of their electrical instruments, resistance boxes and bridges, moving coil galvanometers, and moving coil and moving iron ammeters and voltmeters. The most interesting feature is the winding of the resistance boxes by M. G. Vigneron's modification of the Chaperon winding to reduce inductance and capacity. The winding is on a notched bakelite card, say 100 × 70 mm. and 2–3 mm. thick, and is effected according to the scheme shown in Fig. 1. It will be seen that the currents in adjacent conductors are in opposite directions, as in ordinary anti-inductive windings, but that if we consider the winding as made up of 12 conductors in series, conductors 1–4 are adjacent to 10–7, and 5 and 6 to 12 and 11 respectively, so that the capacity current is considerably

reduced. Twenty such sections are employed in each coil, so that the effective capacity is extremely small. The precision resistance boxes and bridges are of the plug bar decade

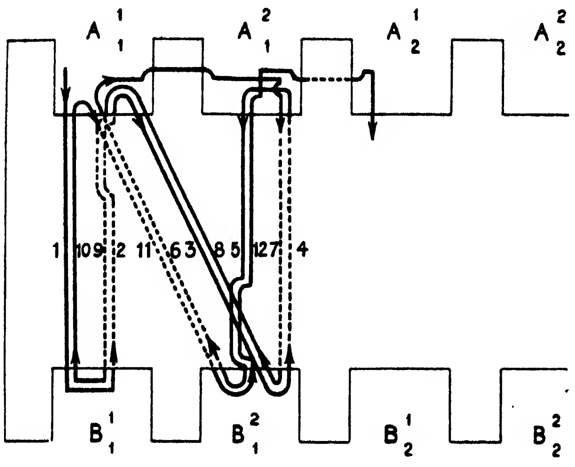


Fig. 1

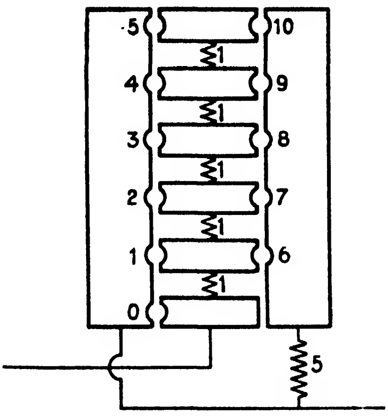


Fig. 2

system, each decade being made with 5 coils of equal value and one of 5 times that value, and apparently connected as in Fig. 2, so that the complete range of 10 units is obtained with six coils.

THE NEW HELLIGE COMPARATOR FOR THE DETERMINATION OF HYDROGEN ION CONCENTRATION. By F. ANSELM, D.Sc.

THE weighing methods generally applied for the above determination have always been very trying. This new comparator, made by F. Hellige and Company, of Freiburg, avoids these methods, and allows a much simpler, quicker and more accurate mode of working. Besides this, the *liquid* standard colour solutions can be dispensed with, and for them are substituted standard colour *test plates*, made of glass optically worked, and very accurately matched. It goes without saying that these test plates are of far greater durability than the old standard colour solutions, which too easily alter. When using the new comparator, the tests are based on standard values, and comparison between single tests is possible at any time, even if performed separately as regards locality and time. Moreover, the new colour plates have the advantage of far greater accuracy of reading than the colour solutions.

The new comparator consists chiefly of a metal housing containing a revolving metal disc with a number of round standard glass test plates (Fig. 2) disposed in a circle, and of a prism by means of which the two colour fields are made to appear juxtaposed. The troughs supplied with the comparator are vitrified acid-proof, and can therefore be used for all solutions; they have plane-parallel walls and give accurate images free from distortion.

The colour plates are combined according to the subject of the test, its reaction-colour and self-colour, and the gradations of the single plates as regards colour depth and colour tint are made according to the accuracy required. This accuracy can be increased to such a degree that the slightest variations of colour perceptible to the eye can be registered with ease. In all other respects the determination of hydrogen-ion concentration by means of

the Hellige Comparator is based on the well-known indicator method and, on the whole, carried out in exactly the same manner as with apparatus using colour solutions, except for the advantage that the determination with the new comparator is of a materially simpler and more accurate kind.

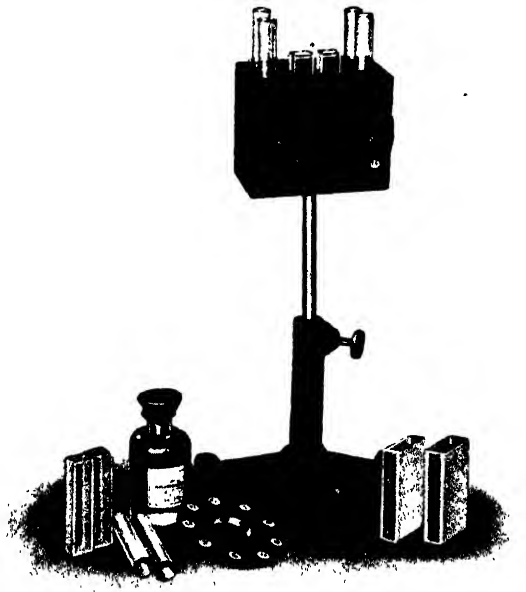


Fig. 1. The New Hellige Comparator

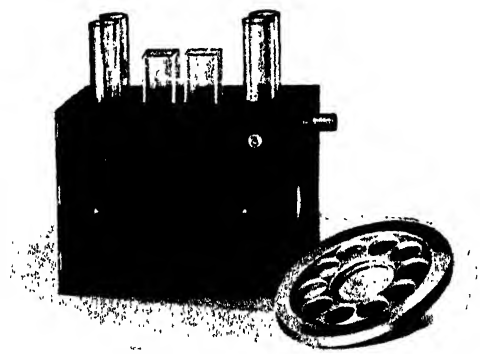


Fig. 2

A series of colour plates for a number of different determinations has already been worked out, especially for:

1. Determination of the pH values according to the indicator principle, in urine, serum, culture media, alimentary broth, sugar, syrup, glue, gelatine, milk and milk products, leather, rubber, foodstuffs, vegetables, meat and fruit preserved and canned, bread, pastries, etc.

2. Determination of the colour of beer, ale, malt and condiments, as well as for determination of their colorative power.

3. Colorimetric determinations in general: chemico-analytic determinations of metals, such as iron, lead, mercury and copper; determinations of ammonia and of sulphuretted hydrogen, etc.

4. Determination of the degree of refinement of all kinds of oil, petroleum, crude oil, etc.

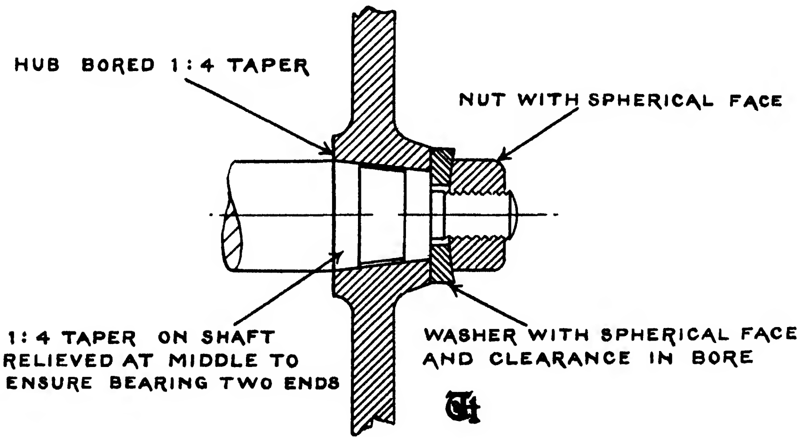
New colour discs for other determinations are in course of preparation.

LABORATORY AND WORKSHOP NOTES

SOME PRACTICAL POINTS REGARDING THE MOUNTING OF A DISC UPON A SHAFT

THE usual method of mounting a disc or the like upon its shaft, where a cylindrical hole in the disc is made a push fit over the shaft, the disc being prevented from rotating either by a key or by clamping it up against a flange, is unsatisfactory in manufacturing practice when accurate centering is necessary.

The illustration shows a better design. Here the hole in the disc is bored out to a taper of about 1 : 4, the mating taper on the spindle being relieved for the middle portion of its length to ensure bearing at two points as remote as possible.



The disc is clamped up by a nut and washer. Owing to the difficulty of ensuring that the face of the nut will be square to the axis of the shaft, its clamping face is made spherical and bears against a corresponding spherical seating in the washer, which is thus allowed to accommodate itself to the face of the hub.

To allow the washer to centre itself, it is essential that it should not be long and that the central hole should be larger in diameter than the screw, to permit the washer to locate itself laterally.

THE TAYLOR-HOBSON RESEARCH LABORATORY.

LEICESTER.

ON A NEW DEVICE FOR THERMOSTAT CONTROL.

By BASIL W. CLACK, D.Sc., Ph.D., F.Inst.P., and H. F. T. JARVIS, B.Sc., Birkbeck College, London.

The following note describes a new device for controlling an electrical thermostat employed in keeping a large tank of water at a constant temperature for long periods.

The bath S is heated by an electrical immersion heater A, the current being switched on or off automatically, as required, by the special relay switch shown diagrammatically at B, made by the General Electric Company. This relay switch is operated by the rise and fall of a column of mercury C, the movement being produced by the changes in volume

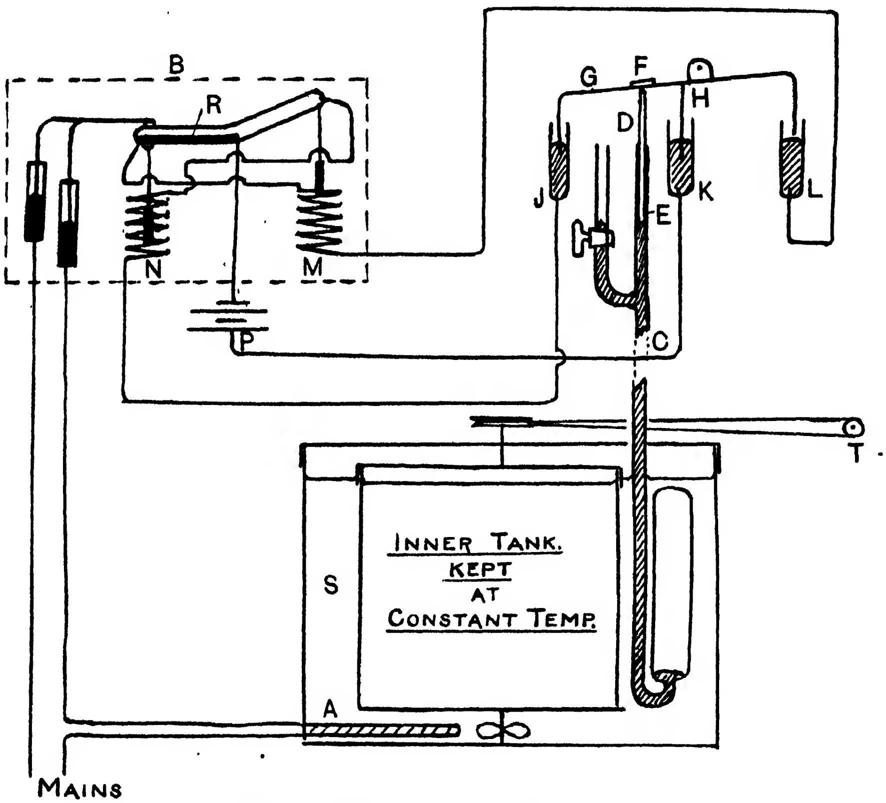


Fig. 1. New Thermostat Device

of a large bulb of toluol, in the usual way. The mercury, as it rises, pushes up a glass piston D, which fits the tube E with very little friction. This piston in turn pushes up a small brass plate F attached to the wire lever G. The lever is pivoted about balance points at H, and is controlled by gravity. It is bent so as to dip into three mercury cups J, K and L. These three points are connected to the relay switch B, as indicated in the figure.

As the piston rises, electrical contact is made between K and L. This causes a current from the dry cells P to flow through the pool of mercury R and the coil M, which pulls the relay switch B down on the right, the battery circuit being at once broken by the flow of mercury R in the switch from left to right. The main circuit is simultaneously broken, and the heat cut off.

As the bath cools, the mercury column falls until electrical contact is made between the

points *J* and *K*. This causes a momentary current to flow through the coil *N*, and the relay switch is pulled down on the left, the battery circuit being again immediately broken by the flow of mercury *R* from right to left. The heat is thus switched on again.

By adjustment of the position of the mercury cups *J*, *L*, it is possible to regulate the temperature so that it is kept constant to within $\frac{1}{50}$° C. or less. This device has been in use satisfactorily for over a year, and during some experiments on diffusion, the apparatus was kept running continuously for over a fortnight, during which time the temperature of the bath never varied by more than $\frac{1}{50}$° C.

The advantages claimed for the method are:

1. Extreme sensitiveness when necessary.
2. Capability of running for long periods without attention.
3. Apparatus is positive both on heating and on cooling, the relay switch operating both at make and at break. There are no armatures or springs to require adjustment.
4. No carbon blocks or rods to wear or burn away.
5. No sparking occurs at contacts *J*, *L* on breaking the relay current—the break takes place in the glass tube *R* of the switch, which is evacuated.
6. Ease of adjustment to various temperatures.
7. Long life of relay battery, since current is only supplied for a fraction of a second at each operation of the switch.

CORRESPONDENCE

COST OF ENGLISH INSTRUMENTS

I NOTICE in the *Journal* a letter from Sir William Napier Shaw on the difficulty he had in getting any English firm to manufacture an Aitken Dust Counter.

Comments of this kind, which are made from time to time, are not always fair to the English instrument maker, and I can the more readily point this out, as in this case I believe my firm had nothing whatever to do with the matter.

Where this Aitken dust counter originated, I do not know, but I imagine the demand for it cannot be very considerable. In that case the original maker is probably able to outbid any other manufacturer. If the original maker had been an English maker (and I judge that he was not) then I think the case would have been reversed and that he would have been able to supply at a price much lower than that quoted from any other country.

If I am wrong in my assumptions, it will be waste of space to publish this letter in the *Journal*, but if I am right, then I think that in justice to English instrument manufacturers and to Englishmen, it ought to be published.

WM. TAYLOR.

STOUGHTON STREET WORKS,
LEICESTER.

(1) In the April *Journal* I made no complaint of being unable to get an Aitken dust counter myself. I quoted a complaint from a letter that had reached me from Australia.

(2) It is quite true, as Mr Taylor says, that the demand for Aitken dust counters is not very considerable. "'Tis true, 'tis pity; and pity 'tis 'tis true." The instrument was designed some forty years ago by John Aitken, not in England certainly, nor in the United States; but in Scotland, in Falkirk, probably, or in Lord Kelvin's laboratory. Who the original maker was I do not know. Some years ago, I obtained one from Lord Kelvin's firm, Kelvin,

Bottomley & Baird, Ltd., I think it was at the time. Having invented the instrument, which illustrates a very important physical principle then little known, but now known all over the world, Aitken made a number of dust counts in many conditions and many countries; but, with the exception of the Ben Nevis Observatory, I know of no place in Britain in which it has been regularly used. I doubt if any considerable number of physical laboratories use it either for practical purposes or to illustrate its principle.

I have heard of dust counts made with it in Germany, in Java and in Australia; but not of any made in England. It is something of a reproach to British physical science that an instrument with its history should be so little used that a prominent British firm of instrument makers should know nothing about it.

(3) I am further impressed by Mr Taylor's remark that "the demand for it cannot be very considerable." An instrument maker not infrequently creates a demand by making an instrument. If he always waits for the demand before he makes the instrument he may find the makers of other countries in the field before him. So, if I may sum up the position which my Australian correspondent points out with regard to the Aitken dust counter, I should find in it first a lack of appreciation of British merit on the part of British science; and secondly, a lack of enterprise on the part of British instrument makers in not realising that demand depends to some extent upon facility of supply.

It is only one example out of many that I have come across of British people being shy of displaying the confidence in British science which it really deserves.

Being accustomed to forecasting, I think I might use that faculty in this connexion. An instrument has recently been installed at the new magnetic observatory at Abinger by which the intensity of the earth's magnetic field—a most interesting and mysterious phenomenon—can be measured electromagnetically in 5 minutes. The traditional method of making the measurement takes at least half a day. In view of the importance of the subject an instrument of the new kind ought to be at least within reach of the students of physics at the universities of this country. I am bold enough to forecast that our educational authorities are more likely to tolerate the expense of constructing a new and different instrument to local design in the local workshop "in order to illustrate the method" than to buy a real working instrument, from the maker who has the patterns, in order to get workable information about the earth.

NAPIER SHAW.

10, MORETON GARDENS, S.W. 5.

DRILLING GLASS AND EBONITE

ANYTHING that Mr Boys writes on laboratory arts is always interesting, and his note in your last issue raises some points on which I may contribute usefully. I am glad to see his commendation of the classic work of Holtzapffel, which has been one of my friends for many years.

As to the lubrication necessary in cutting hard materials by means of tools armed with diamond dust; when, many years ago, we investigated the subject of sawing glass in this way, we began, on Holtzapffel's recommendation, with "oil of brick," but very soon found that common paraffin oil was more effective and less expensive. Later we found that the objection to paraffin oil, namely, that it saturated the floor around the machine, and the workman's clothing, and rendered them inflammable, could be surmounted by using one of the soapy water mixtures sold as "coolants" for cutting tools. This is now pumped on to the tools of the glass sawing machines in a fairly heavy stream and is just as good as oil of brick.

As to drills, and the blunt cross ridge which forms the point of any ordinary drill, and which, as it cannot cut in a strict sense, offers great resistance to the penetration of the drill, there is no drill so perfect in this respect as the half-round drill. In my youth one variety of this was known as the "D bit" or "Woolwich bit." Its working end was semi-cylindrical; its cutting edge extended on a radial line to the very centre of the hole which it drilled, so that every part of the metal removed was cut in a strict sense; and it had the further virtue that its semi-cylinder was urged to, and guided by, the part of the hole already formed, and the drill would never "run," provided it started accurately. It was sharpened by grinding on the end. It inevitably had a 90° cutting angle (that is, it could not have top rake, like a twist drill), and could not withdraw its chips from the hole to the extent to which a twist drill does this. But for materials which require a tool without top rake, and for holes which are not too deep, there is no more perfect tool than the half-round drill. It may be ground with a conical point, after the manner which I devised for grinding conical pointed engraving machine cutters, that is, the drill is rotated on its axis and is presented to a moving abrasive wheel in such a way that a cone is ground on the end of the drill, but the drill is not rotated completely. It is stopped short of complete rotation so as to leave the cutting edge of the drill more prominent than the rest of the cone at the drill end, and to give front rake to the cutting edge; but the point of the cone is in the axis of the drill, and such a drill will not wander from the point at which it is started. The half-round drill has this further virtue, that it is much kinder to jig bushings than is the ordinary twist or straight flute drill.

As to working ebonite, in my apprentice days I made a set of half-round drills of brass, and a set of brass taps, which certainly worked in ebonite better than did steel tools. We are told by archaeologists that in the Bronze Age there was a secret of hardening bronze, which secret has been lost. Was there any secret, and was the bronze really hardened? The fact is, one can more easily make a good cutting edge on bronze or brass than on steel, and this is sufficiently proved by the fact that workers in brass are every day cutting their fingers deeply without at first knowing it, and cutting them with the sharp edges and burrs on their brass work, whereas workers in steel do not have the same experience, and when they cut their fingers always know it at once, by the smarting pain of a torn wound.

WM. TAYLOR.

STOUGHTON STREET WORKS,
LEICESTER.

REVIEWS

Photographic Facts and Formulas. By E. J. Wall, F.C.S., F.R.P.S. (Chapman & Hall, Ltd.) 16*s*. net.

The volume contains formulae necessary for the working of nearly all the photographic processes, and in addition recipes for the manufacture of safelights, silvering of mirrors, varnish for negatives, retouching medium, mountants and for many other miscellaneous operations in photographic technique. The important sections on developers and development and also the one on exposure are well treated, and include short, but very clear, explanations of the time, temperature and factorial methods of development, and a useful list of plate speeds in the various systems. A method of exposure is also given in the book, together with working details.

The formulae, as explained in the introduction, are given in the metric system and also in English measure; the latter, however, are not strictly equivalent, as they are based on the principle of 480 grs. to the fluid oz. or 1 gr. per minim, instead of the more usual practice of 1 oz. of 437·5 grs. The list of reducers and intensifiers does not claim to be exhaustive, but all the reliable methods are included, and many useful hints are given as to the most suitable ones to employ for any specified case.

The book throughout gives all essential working details of the more important or difficult processes, and in spite of the need for compression, nothing of significance in the instructions appears to have been omitted. The volume concludes with a series of useful conversion and other tables and is fully indexed. The book may be thoroughly recommended as an up-to-date work of reference on photographic practice, and if in a subsequent edition more reference could be made to well-known makes of photographic material of English manufacture its usefulness would be considerably enhanced.

W. H. W.

Physics Measurements. By ERVIN S. FERRY in collaboration with O. W. SILVEY, G. W. SHERMAN, Jr. and D. C. DUNCAN. Vol. I. Fundamental Measurements, Properties of Matter and Optics. Second Edition, revised. Pp. xii + 288 with 162 diagrams. (Chapman & Hall, London.) 12*s*. 6*d*. net.

The volume under review is the first volume of the new edition of Professor Ferry's *Physics Measurements*, which was first published in 1918. The aim of the book is to furnish the second year College student of pure or applied science with a self-contained manual of the theory and manipulation of those measurements in physics which bear most directly upon his subsequent work in other departments of study and upon his future professional work.

Fifty-one experiments are described, and the aim of the author appears to have been satisfactorily achieved for the most part. The majority of the experiments require no knowledge of mathematics beyond trigonometry and elementary algebra, though in a few, where the methods of the calculus would result in economy of time and mental effort, such methods have been employed.

The section dealing with photometry will probably give the impression that photometry is hardly an exact science. The photometric measurements described depend little on theory and very largely on attention to extraneous details, and this aspect of the experiments does not seem to have received adequate treatment. We should have thought that the determination of mean spherical candle-power was most conveniently done by taking the photometric measurements at the so-called Russell angles, whereby the mean spherical candle-power could be deduced by simple averaging, without the necessity of multiplying by a cosine.

Wollaston is spelt incorrectly in several places.

The form of the book and the quality of the illustrations leave nothing to be desired. Apart from a few minor criticisms the work represents a very creditable performance, and should continue to find extensive use both by students and teachers of laboratory physics.

H. B.

Two Lectures on the Development and Present Position of Chemical Analysis by Emission Spectra. By F. TWYMAN, F.R.S., F.Inst.P. Pp. 43. 8vo. 17 Figs. Adam Hilger, Ltd., 1927. Price 2*s*. 6*d*. net.

Mr Twyman has performed a useful service in the publication of these lectures, which describe in the simplest manner the methods and apparatus used in spectroscopic methods of chemical analysis. As he points out, the extreme sensitiveness of these methods makes their usefulness for *quantitative* work somewhat limited, and, in spite of the pioneer work of Hartley and de Gramont, the further development of the technique has been neglected. These lectures cite sufficient special cases to show that the possibilities of such developments, especially in such fields as metallurgy, are almost unbounded.

Lecture II deals with the production, observation, and photographing of spectra. "Arc" and "spark" methods are adequately described, but it seems that justice is not done to the possibilities of semi-quantitative analysis with high temperature flame spectra. Hartley and Ramage* used this method to control all stages of the isolation of gallium from ironstone, employing a quartz spectrograph, and this is only typical of many other very useful pieces of work by the same experimenters, from which it would appear that the statement made on p. 28, "Flame spectra are of value only in identifying the alkali and alkaline earth metals with the addition of indium and thallium," seems hardly justified. The near ultra-violet spectrum is of some importance and it is doubtful whether "a visual spectroscope is all that is required."

If it fulfils its purpose well this book will soon require enlargement.

L. C. M.

* *Proc. Roy. Soc.* **60** (1897) 406.

The Polarimeter, a Lecture on the Theory and Practice of Polarimetry. By VIVIAN T. SAUNDERS, M.A. Pp. 31. 8vo. 15 Figs. Adam Hilger, Ltd., 1927. Price 1*s*. 6*d*. net.

A most interesting introduction to the subject. The lecture begins the discussion from the historical standpoint, dealing concisely and clearly with the work of the pioneers, Malus, Biot, and the rest, and leads on to the description of modern polarimeters. It certainly should stimulate the interest of any chemist who has to use such instruments, but we are not sure that enough would be gained by abandoning the well-established conventions of right- and left-handed rotations to justify this course, even though the conventions of chemists and physicists may differ. The chemist will of course read more regarding saccharimetry, but the existence of an international sugar scale different from the French one should have been mentioned.

L. C. M.

Lens Computing by Trigonometrical Ray Tracing. By Col. GIFFORD, F.R.A.S. 81 pp. Macmillan & Co., Ltd. Price 7*s*. 6*d*. net.

This is a small book giving an account of the methods used by the author for designing lens systems. His system of ray tracing is founded upon that of Steinheil and Voit.

The first part of the book gives a brief description of the terms used in geometrical optics and the defects which occur in lens systems, while the second gives a fuller account of ray tracing, with several fully worked examples of traces through some standard systems.

The author makes no attempt to show how the formulae he uses are derived, and includes several purely empirical ones which he has found from experience to simplify some of the trial and error work.

The book gives little indication to the beginner as to how to commence a new design of which he has no experience, and does not show the student why the different types of lenses—object glasses, eyepieces, etc.—take the form they do to satisfy the particular conditions under which they are used.

The question of the accuracy which can be expected at the end of a long calculation using, say, seven-figure tables, is emphasised, but it is not shown where this may be entirely meaningless owing to the limited accuracy with which the calculated system can be reproduced in the workshop.

The nomenclature is rather loose and there are a few mistakes in the earlier part of the book.

M. O. P.

Handbuch der Physik. Band XXII: Electrons, Atoms and Molecules. General Editors: H. GEIGER and K. SCHEEL. (Berlin: Julius Springer.) Price: Reichsmark 42, or bound Reichsmark 44.70.

The first 82 pages of Vol. XXII give an account of the properties of the electron, by Gerlach, and form an admirable survey of the subject. Much of our knowledge in this branch is due to the labours of British scientists—J. J. Thomson, Rutherford, Townsend, H. A. Wilson—and it is therefore extremely interesting to have their contributions woven into one homogeneous whole with the work of the continental physicists such as Meyer, Regener, Gerlach, Böhr, Sanzenbucher, Wiechert, Lenard, Busch, Kaufmann, Bucherer, Hupka. The second chapter is devoted to Atomic Nuclei, by Philipp. Here we find a summary of the work of Rutherford, Geiger, Marsden, Chadwick and Moseley. A concise account is given of the work of J. J. Thomson and Aston on isotopes. Following on a description of experiments bearing on α, β and γ radiation, a theoretical sketch is given of the atomic model of Rutherford and Chadwick published in 1925.

Radioactivity is the subject of a monograph by Bothe; this is followed by a monograph by Stefan Meyer, whose article contains very comprehensive tables of the radioactive constants. Karl Przibram deals with ions in gases, and here one finds an excellent account of the various methods devised for measuring mobilities, diffusion, etc. The size and structure of the molecule is the subject of an interesting article by Herzfeld and Grimm. In this section a vast amount of material is admirably sifted so as to show its bearing on the main topic. The volume is concluded by a monograph by Paneth on the system of the elements.

Taken as a whole, the book is an excellent résumé of the subject over the period 1900 to 1925. One notes a few blemishes. For example, no reference is made to Raman's work in dealing with scattering of light by gas molecules on page 489. No reference is given in the index to authors unless their names are associated with some law or apparatus. Consequently, one cannot find the name of Rutherford in the index, although it appears very frequently in the text. A subject which one might have expected to find dealt with is the passage of α particles through matter, but this has been reserved for another volume in the series.

The book contains a page of physical constants, dated 1926. It is interesting to note that the values given for fundamental constants differ appreciably from those given in the volume of the International Critical Tables. E. G.

INSTITUTE OF PHYSICS

PHYSICS IN INDUSTRY. TWELFTH LECTURE: PHYSICS IN THE GLASS INDUSTRY

THE twelfth lecture of the series "Physics in Industry" was given to the Institute of Physics on May 25th, in the rooms of the Institution of Civil Engineers. The lecturer on this occasion was Professor W. E. S. Turner, Professor of Glass Technology in the University of Sheffield, and his subject "Physics in the Glass Industry."

Professor Turner gave an account of the application of scientific principles and of the results of scientific research in the manufacture of glass for all purposes. Individual scientists have investigated the properties of glass, among them Fraunhofer and Faraday, whose work on "heavy" glass at the Royal Institution was recalled; but the subject has received little attention in scientific institutions until very recent years. Important research has, however, been initiated in industrial laboratories, with the object of improving the processes of glass-making and of investigating the properties of the material; and the requirements of the War, during which glass supplies were necessarily drawn from sources in this country, have added impetus to this work, particularly as regards optical glass.

Manufacturers have believed, and the belief has been very difficult to eradicate, that correct annealing depends on "baking" the glass; but the recent research on the variation of viscosity with temperature, and in particular the relationship deduced by Twyman, has shown that the rate of cooling is the important factor. Twyman's investigations, undertaken early in the War, have since been extended by the observations of Adams and Williamson in America; and the knowledge gained of the conditions governing the release of stress in glass on cooling has lead to highly important improvements in annealing practice and economy of time in manufacture.

Important results in other directions have been obtained in the University of Sheffield, the National Physical Laboratory and elsewhere, including work on the composition of glass as related to its physical properties.

Three of the principal physical properties of glass are providing fruitful fields of research, namely, thermal expansion, electrical conductivity and optical properties. For example, expansion measurements, as carried out at the Research Laboratories of the General Electric Company, have led to improvements in the manufacture of electric lamps; while observations of the absorptive properties of glass for radiation in different parts of the spectrum have led to the introduction of special glasses for therapeutic and other purposes, for example the Vitaglass of Messrs Chance Brothers.

JOURNAL OF SCIENTIFIC INSTRUMENTS

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ON THE USE OF THE ELECTROMAGNETIC RECEIVER IN ACOUSTICAL MEASUREMENTS.

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[*MS. received*, 17*th April*, 1927.]

ABSTRACT. The advantages of the electromagnetic receiver as a microphone, in sound measurements, are discussed. It is pointed out that the sensitiveness of the moving-coil receiver is much more constant than that of the moving-iron variety, and reasons for this are given. A modification of the usual type of receiver is described, the instrument being rendered sensitive and selective by the use of a tuned electrical circuit, and an arrangement is also given by means of which errors, due to stray electromagnetic disturbances, can be eliminated. The single receiver, so modified, has a high sensitiveness over a frequency range from 200 to 2000, and variations in sensitiveness are not more than one per cent., provided certain precautions are taken.

THE main advantages of the use of electromagnetic receivers in determinations of sound intensities lie in the wide frequency and intensity range over which such instruments are sensitive. By comparison, most other intensity measuring instruments have a very limited range of frequency, and even when they are tunable the range is still very narrow. Moreover, the sensitiveness of electromagnetic receivers, when used in conjunction with valve amplifiers, is generally not less than that of other types and can usually be made much greater.

Receivers of the electromagnetic type can be divided into two main classes, differing in the way in which the transformation from mechanical to electromagnetic energy takes place. In one type, the moving-iron variety, an electromotive force is generated in the coil surrounding a permanent magnet, due to the movement of an iron diaphragm in the field of the magnet. In the other class, a non-magnetic diaphragm is used, to the centre of which is attached a small cylindrical coil of copper wire. When the diaphragm is forced into vibration the coil of wire moves at right angles to the lines of force of a constant magnetic field, and an electromotive force equal to the rate of change of magnetic flux is generated in the coil.

It is usual to name these two classes of receivers the *electromagnetic* and *electrodynamic* types respectively. This, however, is an unfortunate nomenclature, since both are obviously electromagnetic and each, having a moving armature, can be called electrodynamic. A more suitable name for the first kind would be the moving-iron type, and the latter might be called the moving-coil type. The essential difference between the two receivers is that in the moving-coil type the reluctance of the air gap in the magnetic field is constant, whereas in the moving-iron type, the reluctance is variable, depending on the position of the diaphragm during its vibration.

Practical Considerations

We may proceed to consider those characteristics of a receiver that are essential for the purposes of sound measurements. The receiver should be constant and sensitive, and it is generally advantageous to make it selective, so that adventitious influences outside the frequency of the sound that is being measured are not serious.

Let us now consider each type of receiver in detail. Fig. 1 is a diagram of a receiver with an iron diaphragm. The sensitiveness of this receiver depends on the width of the air gap between the poles of the magnet and the diaphragm. Of the factors which can alter the width of this gap, two are important, namely, the effect of temperature, and the clamping conditions of the diaphragm. Changes in the temperature might seriously alter the width of the gap by altering the size of the diaphragm, but this effect will normally be minimized by the simultaneous expansion or contraction of the case, depending on the relative coefficients of expansion. Temperature changes might also alter the elastic constants of the diaphragm. It is found in practice that if such a receiver is warmed slightly, the sensitivity does in fact alter appreciably. With some receivers, the diaphragm, when cold, may be in actual contact with the pole pieces, but when warmed slightly, for example, by being worn on the head, the diaphragm can be heard to leave the pole pieces.

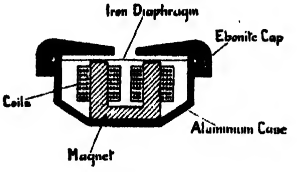


Fig. 1

It is customary, in this type of receiver, to use an ebonite cap for clamping purposes. An insulating material is necessary, in particular, when the receiver is applied to the ear, for listening purposes. The use of ebonite, however, does not contribute to constant sensitivity, as owing to its elastic properties it is incapable of exerting a constant clamping force at the boundary for long periods. In electromagnetic receivers, electromechanical efficiency is usually very small, of the order of 0·1 per cent., and it is sometimes assumed that a large amount of the energy supplied is dissipated in losses at the clamping edges *. If we may assume that whatever energy is not lost in such losses, goes into mechanical energy of the diaphragm, it follows that a small percentage change in the edge losses will mean a large percentage change in the energy of the diaphragm, and therefore a large variation in sensitiveness.

From this reasoning it would seem that a material such as ebonite is unsuitable for diaphragm clamping. Owing to its large variation in sensitivity a moving-iron receiver was found to be of little value in precision sound measurements. The ebonite cap was replaced by one of brass or aluminium †, as shown in diagram Fig. 1 A, and the performance was greatly improved, but finally the receiver was abandoned in favour of the moving-coil type.

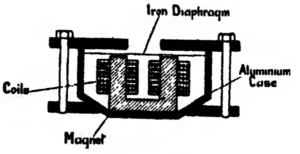


Fig. 1 A

Consideration of the principle on which the moving coil receiver works indicates its superiority for measurement purposes. The coil is in a magnetic field of fairly uniform flux density. The E.M.F. generated in the coil, when the diaphragm is in motion, is equal to the rate of change of flux, and consequently a slight alteration in the zero position of the coil will not sensibly affect this E.M.F.‡ The diaphragm, which is of metal, is clamped between two metal supports. The only way in which temperature can make an alteration in the sensitivity is by altering the elastic constants of the dia-

* L. V. King, *J. Franklin Inst.* **187** (1919) 624.

† Cf. Mallett and Dutton, *Journ. I.E.E.* **63** (1925) 502.

‡ Even if the field is not constant over the whole dimensions of the coil, the increase in the field at one end would be more or less balanced out by the decrease at the other. It will be assumed in what follows that we can replace the actual field by a uniform field.

phragm. Such a receiver has been used extensively in the work in the Physics Department of the National Physical Laboratory, and it is considered that a description of its manipulation and characteristics may be of interest. The actual receiver described is part of a commercial loud speaker.

A diagram of the receiver is shown in Fig. 2. The magnet case consists of a shell of wrought iron, and the central core and ring-shaped pole piece are made of soft iron. The core is accurately centred so that there is an air gap of about 1/16 inch between the pole and the ring. Round the iron core is wound a magnetizing coil which consists of about 1000 turns of No. 18 S.W.G. copper wire. The magnetizing current required is usually between 0·5 to 1·0 ampere. The nickel-silver diaphragm, which is clamped between metal rings by means of eight screws, has a small cylindrical coil fastened to its centre. This coil, which is wound on an ebonite former of about 3/4″ diameter, consists of about 100 turns of No. 40 S.W.G. copper wire, the resistance being about 10 ohms.

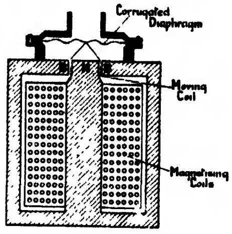


Fig. 2

Use of the Receiver

When the receiver is placed in a field of sound, the diaphragm is forced into vibration of the same frequency as that of the sound, the actual amplitude of vibration being proportional to the pressure-amplitude of the sound. The coil, moving with the diaphragm, cuts the lines of induction of the magnetic field at right angles, and an E.M.F. is generated in it.

If we represent the diaphragm motion at its centre by

$$x = A \cos \omega t \qquad \ldots\ldots\text{(i)},$$

and if N = flux density at cylindrical area of coil, the E.M.F. generated in the coil is given by

$$e = 2\pi rnNA\omega \sin \omega t \qquad \ldots\ldots\text{(ii)},$$

where r = radius of coil and n = number of turns.

As the E.M.F. varies as the total length of the wire forming the coil, it is advantageous, when designing such an instrument for use as a microphone, to wind the coil with as large a number of turns as possible, provided the weight of the wire is not prohibitive.

In its original form, the moving coil of the receiver is connected to the low-resistance primary of a high-ratio step-up transformer. The receiver can be used in this form as a microphone for acoustic exploration, in which case the E.M.F. generated in the secondary of the transformer is a measure of the acoustical pressure amplitude for a constant frequency.

A method used for measuring the E.M.F. has been described in a previous paper *, and consists in comparing the E.M.F. with another known E.M.F. obtained from the secondary of a variable mutual inductance. The E.M.F.'s to be compared are applied alternately to the input of a resistance-capacity coupled amplifier, in the output of which is a rectifying device. The known E.M.F. is varied until it is equal to that generated in the microphone. When the moving-coil receiver was used in its original form, it was found that the E.M.F.'s from the two sources were not equally pure, and the cause was found to lie in the use of the iron-core transformer, which presumably was introducing distortion. The difficulty was overcome by dispensing with the transformer. In this form the receiver was much less sensitive owing to the loss of the step-up effect due to the transformer, but the sensitiveness was greatly increased by connecting the moving-coil to a large inductance, so that the system could be tuned into resonance with the frequency of the sound by means of a

* *Phil. Mag.* **3** (1927) 181.

variable condenser. This also had the advantage of making the receiver more selective than in its original form.

A diagram of the modified arrangement is given in Fig. 3. The moving-coil c is joined in series with a large inductance coil L and a variable condenser C connected across the whole. The actual E.M.F. measured is that generated between A and B. This is connected across the input of the amplifier of the measuring system. The relation between this E.M.F. and that actually generated in the coil can be worked out very easily as follows:

Let e = E.M.F. generated in the moving coil.
L = total effective inductance of the circuit.
C = total capacity across coil (including self capacity).
R = total effective ohmic resistance of the circuit.

Then the current i, flowing in the circuit, is given by

$$i = \frac{e}{\sqrt{R^2 + \left(L\omega - \frac{1}{\omega C}\right)^2}} \qquad \text{......(iii)},$$

where $\omega = 2\pi \times$ frequency.

If the circuit is tuned to resonance

$$e = i_r R \qquad \text{......(iv)}.$$

Now the E.M.F. E, across AB, is given by

$$E = \omega L i_r \qquad \text{......(v)},$$

so that the magnification of the circuit is given by

$$\frac{E}{e} = \frac{\omega L}{R} \qquad \text{......(vi)}.$$

It is therefore advantageous to keep R as small as possible and to use a very large inductance.

As an illustration, the magnification can be worked out in the case of an arrangement that has been used in experimental work. In this case the resistance of the microphone coil, plus the resistance of the inductance coil used, was 18 ohms, and the inductance was about 1/3 henry. At a frequency of 1000 the magnification of this arrangement was therefore about 115.

As mentioned previously, the inductance coil in the above arrangement must be very large in order that the receiver shall be very sensitive. It is therefore liable to "pick-up"

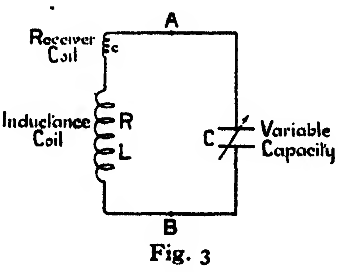


Fig. 3

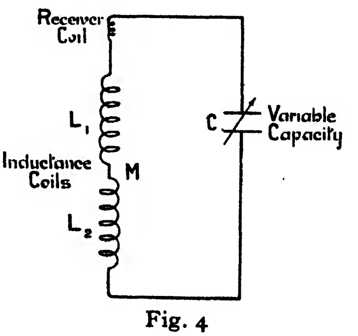


Fig. 4

inductively any stray electromagnetic fields from neighbouring apparatus. If these parasitic effects are of a frequency far removed from the frequency of the sound, the tuning arrangement minimizes their effect and usually they can be rendered negligible. The effect can be eliminated entirely, however, by so disposing the inductance that there is no "pick-up,"

a precaution which is essential when the disturbing error is of the same, or nearly the same, frequency as the sound. The plan proves ineffective, however, when there is more than one disturbing source, since twisting the coil to eliminate one source may cause it to pick up from another.

To overcome this difficulty the method is modified slightly. A diagram of this modified arrangement is given in Fig. 4. The inductance L is replaced by two inductances L_1 and L_2 of equal size. They are placed at a slight distance from each other, with their axes parallel and with corresponding plane ends in the same plane. In this arrangement the coils will have a certain mutual inductance M. The effective inductance of the circuit is then equal to L_1+L_2-2M or L_1+L_2+2M, depending on whether the coils are joined in opposition or conjunction respectively. With the former arrangement, stray electromagnetic effects due to distant sources are equal in both coils, but their phases are exactly opposite and therefore they neutralize each other. Any stray fields are thus eliminated. In practice this arrangement has been found to work excellently.

When a disturbance is due to an electrostatic "pick-up" from some source, screening the coils by metal boxes is effective.

When very loud sounds have to be measured, and when experimental work can be done at a distance from disturbing influences, stray effects need not be considered; but when the amplitude of the sound to be measured is very small, as is the case with sound transmitted through thick materials, such disturbing effects may be very considerable. In fact, the accuracy with which feeble sounds can be measured in practice is determined by the magnitude of the parasitic effects. It is therefore of importance to minimize these effects by the means described above, and furthermore, to increase, if possible, the sensitiveness of the receiver.

To this end, the plan has been adopted of converting the reservoir of the receiver into a tuned resonator, by the use of a number of cylindrical caps made to fit tightly on to the mouthpiece, and having various sizes of apertures. The device not only increases the sensitiveness enormously at the various resonant frequencies, but enhances the acoustical selectivity of the receiver.

In order to ensure that the sensitiveness of the receiver is constant for long periods, certain precautions are necessary. The current recommended for magnetizing the iron core is not sufficient to saturate it. In fact, a current of about three times the normal current is required, but such a large current cannot be used as it causes appreciable overheating of the receiver. Under these circumstances adequate precautions are necessary to keep the magnetizing current constant, for which purpose an ammeter and an adjustable resistance in the exciting current circuit are advisable. Owing to the appreciable hysteresis of the soft iron, the strength of the magnetic field varies with the direction of the magnetizing current, and it is necessary to arrange that this current always flows in the same direction.

A single receiver so modified may in this way be given very high sensitiveness over a frequency range as wide as from 200 to 2000. At the resonant frequencies, amplitudes of the order of minimum audibility for the ear can be measured when suitable amplification is used. Variations in sensitivity over long periods have been found to be not greater than one per cent.

In conclusion, I desire to thank Dr G. W. C. Kaye, Superintendent of the Physics Department, for his helpful criticism and advice. I am also indebted to Dr A. H. Davis for his cooperation in the work.

A VARIABLE BI-FILAR SUSPENSION FOR QUARTZ FILAMENTS. By W. H. DEARDEN, M.Sc. (Metallurgical Department) Royal School of Mines, London.

[*MS. received, 16th March*, 1927.]

THE chief difficulty in the use of measuring instruments which contain highly sensitive suspended systems lies in the variable position of the "zero." This position, as is well known, depends on the directive forces exerted on the system. These are to some extent capable of variation by the user of the instrument, or, in other words, there is a "zero adjustment," but it is clear that they must afterwards remain constant if consistent behaviour is expected of the "zero."

It is usual with modern highly sensitive needle galvanometers to suspend the needle system on a quartz filament so fine that the directive force exerted by it is negligible, and then to obtain the necessary force by means of a magnetic field whose strength can easily be varied. This method is, however, unsatisfactory because the slightest change in the strength or direction of the field will produce a corresponding variation in the "zero" of the instrument. These magnetic disturbances do occur even in the case of ironclad instruments, and it is therefore necessary that any directive force exerted on the suspended system should whenever possible be mechanical, and as high as is compatible with the required sensitivity of the instrument. To discover in advance the single quartz fibre possessing the necessary elastic directive force is not generally feasible. The problem can be reduced, however, to the construction of a suspension with a mechanical directive force which can readily be varied at will.

The following is a description of a variable bi-filar suspension which was used in connection with a thermo-magnetic investigation of some carbon steels. A similar type has been thoroughly tested also for needle galvanometers, and may be usefully adapted for other purposes.

The brass suspension head seen in section in Fig. 1 was constructed to make a vacuum-tight fit in a magnetometer of special design, and at the same time, permit both the direction of the suspended system, and the directive force acting upon it, to be adjusted without disturbing the vacuum. This was possible because of the long bearing surfaces between the three parts of the head. Being lubricated with vacuum-grease they could rotate easily relatively to each other, and at the same time they permitted no leakage of air into the apparatus.

The outer conical part A acted as the bearing for the hollow spindle B which had, screwed on its upper end, a large milled disc C. The surface of the disc was divided into a scale of degrees, and a small pointer D, attached to A, permitted the angular rotation of the disc to be measured. In turn B was the bearing for the accurately fitted spindle E which, with its smaller milled head F, was turned down in one piece from a solid rod. Just below the head a pointer, fixed perpendicularly to the axis of the spindle, moved over the scale of degrees engraved on the upper surface of C.

Now, by rotating the head C the entire suspension could be adjusted as regards direction, while the directive force exerted on the system by the quartz filament could be increased or decreased by turning the upper head F. As may be clearly seen in the figure, the outer spindle B was turned and milled down into two arms G, G, which were each bent inwards at the bottom to a knife-edge, in the centre of which was a minute notch, cut to act as a

guide to enable the two parts of the suspension loop to be kept strictly opposite one another even when the knife-edge was closed. The spindle E was considerably reduced in diameter at the lower end, and the fine screw-thread cut there worked in the pear-shaped piece H, which was designed so that it could slide but not rotate. The piece could therefore be raised or lowered, depending on the direction of rotation of the head F. On rising, it came into contact with rounded projections on the arms, pressed the latter outwards, enlarging the knife-edge gap, and thus increased the stiffness or directive force of the suspension. Reversing the process allowed the arms to close, and so made the system more sensitive. A simple calibration made it possible at any time to derive the width of the knife-edge gap from the degrees of rotation of the head F.

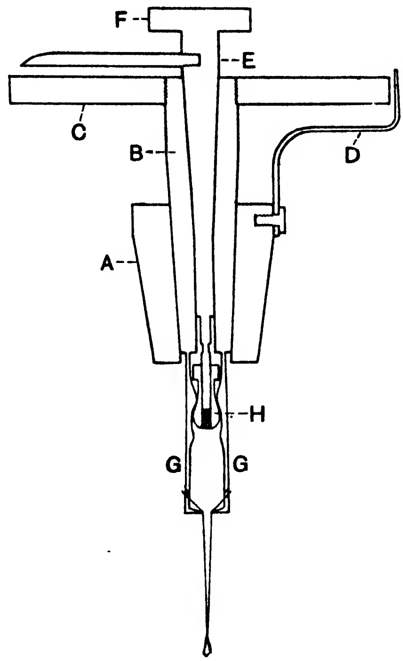


Fig. 1

The loop which formed the bi-filar suspension proper was sealed into two small holes, drilled low down on the arms. This suspension is usually formed by a single fine quartz filament, the advantages of the use of this material being well known. The writer, for various reasons, found it more convenient to use tungsten wire 12 microns (0·012 mm.) in diameter, but the method of mounting this fine wire is exactly the same as that used in the case of quartz filaments, and is, if anything, rather simpler in practice, because the wire can be seen more easily. The following is the technique, described previously by Benedicks*, for mounting filaments in the above type of suspension head.

Any number of the finest filaments can readily be prepared by the very simple process introduced by Nichols (see Kohlrausch, *Lehrbuch der Praktischen Physik* (1921) p. 40). Having selected a suitable one, it is treated as follows:

Cut off two pieces, each about 6 mm. long, from some aluminium wire about 0·1 mm. in diameter. Coat one end of each of these pieces with a little adhesive wax by bringing it into contact with some of the wax melted on the end of a heated piece of thick copper wire. The adhesive wax should have the following properties: (*a*) it should be non-adhesive when solid, (*b*) it should give off no vapours when heated, and (*c*) its melting point should be sharp and easily observable, as for example, by sudden clarification. The adhesive waxes used in dental practice (*e.g.* Ash's Model Cement, melting at about 56° C., and Caulk's Sticky Wax, melting point 66° C.) have proved very satisfactory in this respect.

The quartz filament, selected from a number prepared as indicated previously, is brought on to a glass plate which forms the lid of a box lined with black velvet. This arrangement permits the filament to be seen clearly during the subsequent manipulation. The glass plate must be scrupulously clean, as also must the forceps used to handle the filament: it is generally convenient to dust the latter with talc powder, as this, on a fine fibre, renders it easily visible without doing any harm.

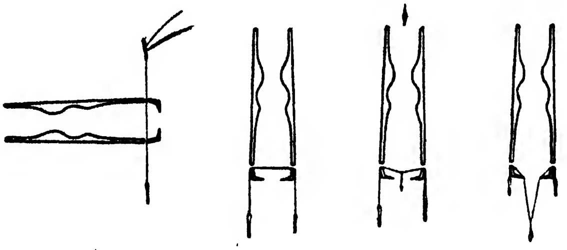
The waxed tip of one of the short aluminium wires is brought against the filament near the end. The wire is gently warmed with a micro-flame†, when the wax will melt and firmly join the wire to the filament. In a similar manner the second piece is fixed, leaving

* C. Benedicks, *Zeitschrift für Instrumentenkunde*, **42** (1922) 367.

† C. Benedicks, *Annalen der Physik*, **55** (1917) 1 (64).

a suitable length of filament between the two. Any free ends of the quartz are cut away with a pair of fine scissors.

In affixing the prepared filament in the suspension head the latter is turned into a horizontal position so that the holes in the arms are in the same vertical line (Fig. 2). The filament is lowered through, as shown at (*a*), and the head now carefully brought into a vertical position so that the filament with its end-pieces hangs as indicated at (*b*). The



(*a*) (*b*) (*c*) (*d*)

Fig. 2

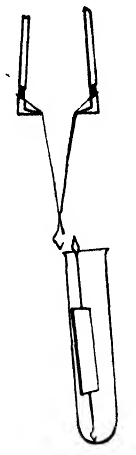


Fig. 3

hook which will carry the remainder of the suspended system can be conveniently made from the aluminium wire used for the end-pieces. It is dusted with talc, held lightly in the forceps, and lowered gently on the filament (*c*). Continue drawing the hook vertically downwards between the knife-edges of the suspension arms until the loop formed by the filament is of the required length (*d*). Carefully adjust the loop in position in the two notches in the knife-edges, mentioned previously.

Before placing the filament in position, a small quantity of wax should be set on each arm in close proximity to the hole. Having then carried out the above operations, it only remains now to fix the filament by slightly warming the two suspension arms successively with the micro-flame, when the wax will melt and can easily be caused to flow into the holes, and so round the filament, making it secure. Finally, the now superfluous end-pieces can be cut away.

The quartz filament being extremely fragile, it is, of course, necessary to exercise the greatest care when the remainder of the delicate moving system is suspended from the small hook. The former should not be hung on with the forceps, but should be freely supported from below, after the manner shown in Fig. 3 which illustrates the method of hanging up a small mirror. This avoids putting the filament under any excessive strain.

The author wishes to express his thanks to Professor Carl Benedicks for permission to describe the above apparatus, which was constructed for him at the Metallographic Institute, Stockholm, by its instrument-maker, Mr C. A. Andersson.

A NOVEL HIGH SPEED CAMERA. By E. B. WEDMORE, M.I.E.E., F.INST.P. (Report Ref. XZ/T 2, received from the British Electrical and Allied Industries Research Association.)

[*MS. received, 1st July,* 1927.]

IN 1922 the Electrical Research Association required a camera to take photographs at the rate of 1000 per second of an object which could not be subjected to artificial illumination. The nearest cameras on the market had a limit of 250 pictures per second, cost £587 to £750, and could only be worked at approximately their maximum speed.

A camera was designed by the writer and built at a small fraction of this sum, on lines which afterwards proved to be much the same as those devised by Messrs Heape and Grylls for the Admiralty, and described in this *Journal* in December 1926. As our camera cost perhaps 1 per cent. of the Heape and Grylls apparatus, is portable, and gives good results without searchlight illumination, it should prove of value in other fields.

Principle of construction. As in the Heape and Grylls camera, all oscillating or jerky motion is avoided by the use of a series of lenses in a rotating disc, which come into action in rotation, travelling at the same rate as the film and passing behind a fixed opening and shutter. If this were all, the opening would have to take the form of a narrow slit, and be arranged to give exposure during only a small fraction of the period during which a given lens and film portion are passing, otherwise motion of the picture on the film would occur with consequent loss of definition; hence the powerful battery of searchlights required with the Admiralty apparatus.

In the camera here described the lenses are all focussed for infinity, that is, to receive parallel rays from the object. A field glass is then inserted in front of the shutter, being of focal length equal to the distance of the object, thus delivering parallel rays from the object. An individual lens, with its portion of film, can be moved in any direction in a fixed plane behind this field lens, and will always pick up parallel rays from any point on the object and focus them on to a corresponding fixed point on the film, *i.e.* the picture no longer moves with respect to the film. By the use of a sufficiently large field lens and shutter, exposure can be continued as long as desired, say, until the next lens is coming into action, or even longer.

Lens system. Actually the field glasses used are common circular spectacle lenses, costing a few shillings apiece, and giving exposure for about half of the interval between successive pictures; but more interest attaches to the camera lenses proper, as instead of the cinema camera type, costing several pounds apiece, single lenses are employed, costing two or three shillings apiece, ground double convex with radii to give minimum spherical aberration, but with no attempt made to correct for other errors, not even chromatic aberration. This is made possible by utilizing only the central portion of the field. The lenses are of about 2 inches focal length, and in ordinary camera practice would be expected to give a sharp plane image on a film nearly 2 inches in one dimension, but in this camera the area of importance is that represented by the size of a three-penny piece, *i.e.* $\frac{5}{8}$ inch diameter, though the film area is $1 \times \frac{3}{4}$ inch, or standard cinema size. The margin outside the $\frac{3}{4}$ inch circle is generally relatively unimportant, except from a pictorial standpoint. With these limitations it is found possible to get useful definition with $f = 2{\cdot}6$, a figure only reached in normal photography by the most expensive lenses.

The sample photographs given below are taken with this aperture, and are subject to further sources of error referred to later, but give quite useful definition over a considerable

area. If the lenses are stopped down, any required improvement can of course be obtained in the central or in the marginal definition. At 100 photographs per second in bright sunlight $f = 8{\cdot}0$ would give an equally bright picture, but it would be better to use $f = 5$ and a shorter exposure.

Films used. The camera is designed for adaptation for use with continuous cinema film, the lenses being spaced at $1\frac{1}{2}$ inch centres. This spacing gives room for adjustable mountings enabling the lenses to be accurately pitched and centred, the idea being to print positives by double printing, so as to fill in the gaps, the standard cinema pictures being at $\frac{3}{4}$ inch centres. In order to save film and expense of construction, the model built is not fitted for continuous feed, but 50 lenses are furnished and film is carried round on the back of the 30 inch disc which carries the lenses. This limits the exposures on one film to 50, and with the electrical release employed all but a few can actually be utilized. The shutter cannot be opened instantaneously, so that, at the highest speeds, it is arranged for the first and last few pictures to overlap. These are not necessarily useless.

Errors introduced. The various optical errors due to the lens system are roughly of the same order, in the central part of the picture, as a further error due to carrying the film on the disc. This method of carrying the film causes a small angular rotation of the film

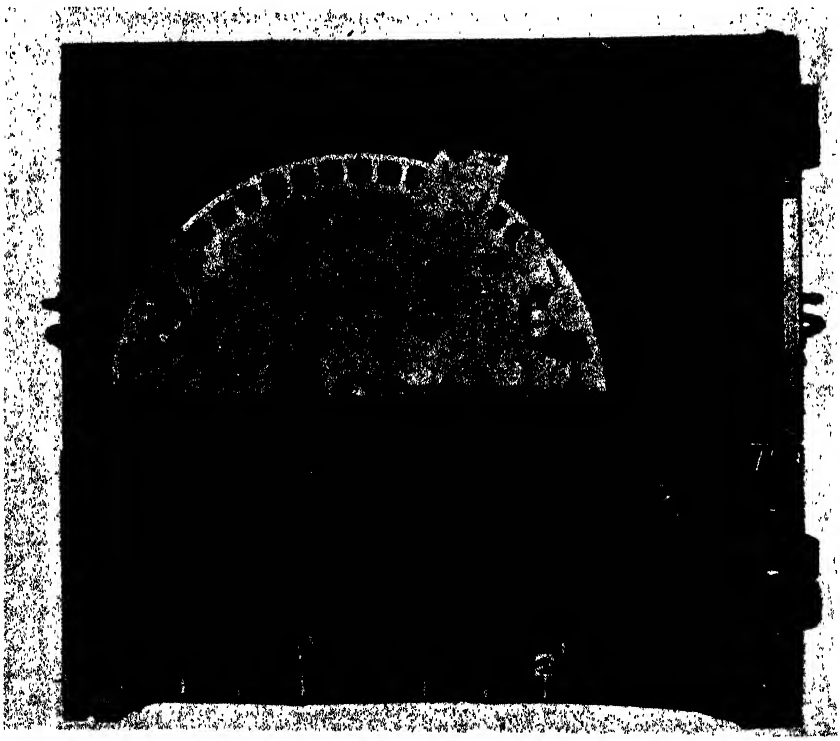


Fig. 1. Back of camera, showing rotating element

during exposure. Angular rotation of the lenses is immaterial if they are properly centred, but angular rotation of the film takes place relatively to the image, and introduces an error of definition, of zero value at the centre of the picture and proportional to the radius. If, however, a band film were used, fed behind the lenses, as in the Heape and Grylls apparatus, there would be a small loss of definition, due to the fact that the lens passes through an arc and not a chord during exposure, and thus the image must move somewhat on the film. In the camera here described the use of the field lens eliminates any error from this move-

ment, which could be quite large, and the number of lenses reduced, if one were satisfied to take fewer than 50 photographs.

General construction. Fig. 1 shows the back of the camera, with a portion of the cover removed. The rotating element is seen, and is mounted on a large bicycle hub bearing and driven by belt from a wheel behind the axle shown on the right. It may be motor driven, but is readily speeded up by hand. The film is in the form of eight sectors, cut from continuous roll and held in place by eight clamps, one of which is shown displaced.

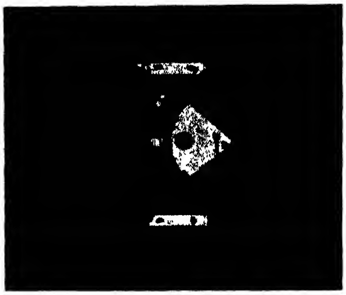


Fig. 2. Part of front of camera showing shutter and release

Fig. 3. Field lens in position

Fig. 2 shows a front view of the camera. The spring operated shutter and the electromagnetic release may be seen. Fig. 3 shows the field lens in position.

Example. As an example of results, three photographs are shown in Figs. 4, 5 and 6, obtained at maximum speed and maximum aperture and, therefore, under the most unfavourable conditions for good definition. A china tea plate was dropped on to a steel anvil in front of a background marked in two-inch squares. The photographs were numbered consecutively in thousandths of a second. In No. 2 the plate hits the anvil. No. 3 shows

Fig. 4

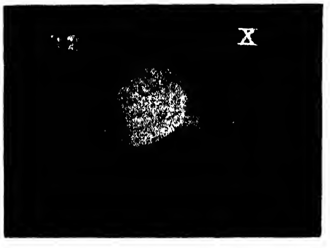


Fig. 5

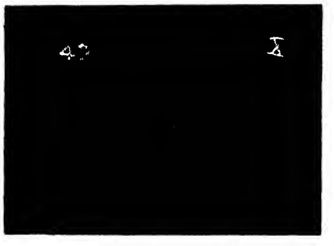


Fig. 6

crushing of the edge and No. 4 a crack started. No. 5, in Fig. 4, shows the crushed edge and the crack, and the plate commencing to bounce. No. 12, seven thousandths of a second later, shows in Fig. 5 the plate still rising on the rebound, the crushed portion also rising as a cloud and the cracked portion falling away. No. 16 shows the cracked portion commencing to turn on its axis, and No. 42, in Fig. 6, shows this clearly. The rebound has reached about one inch and the plate is still travelling upwards in No. 50. The centre of Fig. 6 shows good definition, some of which will, doubtless, be lost in the half-tone block.

NOTE ON THE SIMPLIFIED PRESENTATION OF STEREOGRAMS. By NOEL DEISCH, B.A.

[*MS. received, 15th March, 1927.*]

It is well known that the effect of depth can be had from a stereogram directly, without the aid of any kind of viewing apparatus. With the method as usually practised, however, success is conditioned on adroitness in accomplishing the rather acrobatic feat of simultaneously securing near focus and parallelism, or at best very slight convergence of the optical axes. By transposing the two complementary views constituting the stereogram so as to allow of "crossing" the eyes, however, this initial difficulty is eliminated, the natural fatigue drift of the focus of the eyes away from the point of convergence under these conditions tending automatically to bring the images into focus. The method, which though not new is apparently but little known, has been used for the rapid examination of stereograms in aeronautical work, and it would seem that it should be peculiarly adaptable to the purposes of illustration in books and periodicals, since, contrary to what is the case with anaglyphs, no special inks or viewing apparatus are required.

The accompanying illustrations show the possibilities of the method as applied in optical and instrument work. The first is a stereoscopic diagram of a broken-telescope prism (Fig. 1) recently described by Dr G. W. Moffitt. The construction of the prism is such

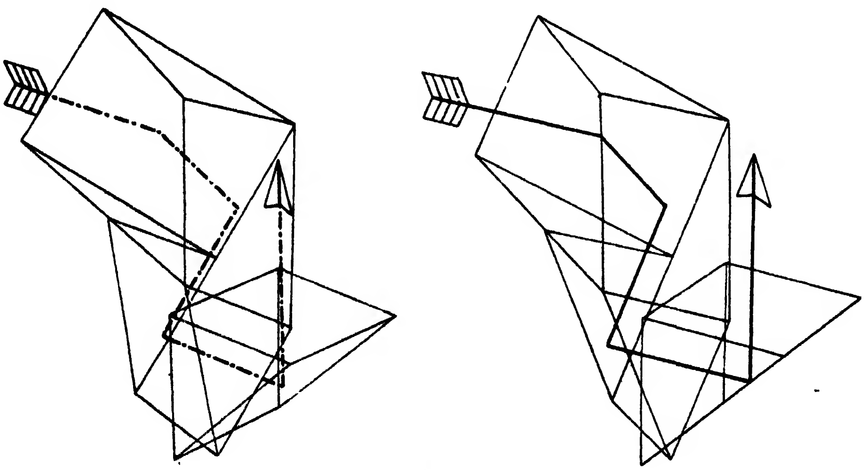


Fig. 1

that it cannot easily be represented in an adequate way by any of the usual projections. In the stereoscopic drawing, however, the positions and inclinations of the reflecting surfaces, together with the path of the central ray, are evident at a glance. The second illustration, a photograph of the miniature Compound shutter mechanism (Fig. 2), gives a good idea of the advantage in clarity that is to be had by recourse to stereograms in descriptions of complex mechanical apparatus.

To those who have not been initiated into the viewing of stereograms without instrumental help it may be stated that the printed surface should be held at about reading distance, in an even light, squarely with the eyes, and that the common horizontal axis or base line of the views should lie parallel with the common horizontal axis of the two eyes.

This latter condition should be more closely adjusted after the stereo relief is perceived by slightly rotating the paper in its own plane until the position of greatest comfort is secured. In the method now under consideration the optical axes are made to intersect in front of the plane of the paper by "crossing" the eyes. On a first essay it may be found convenient to regard an imaginary point located midway between the eyes, and at a distance of about

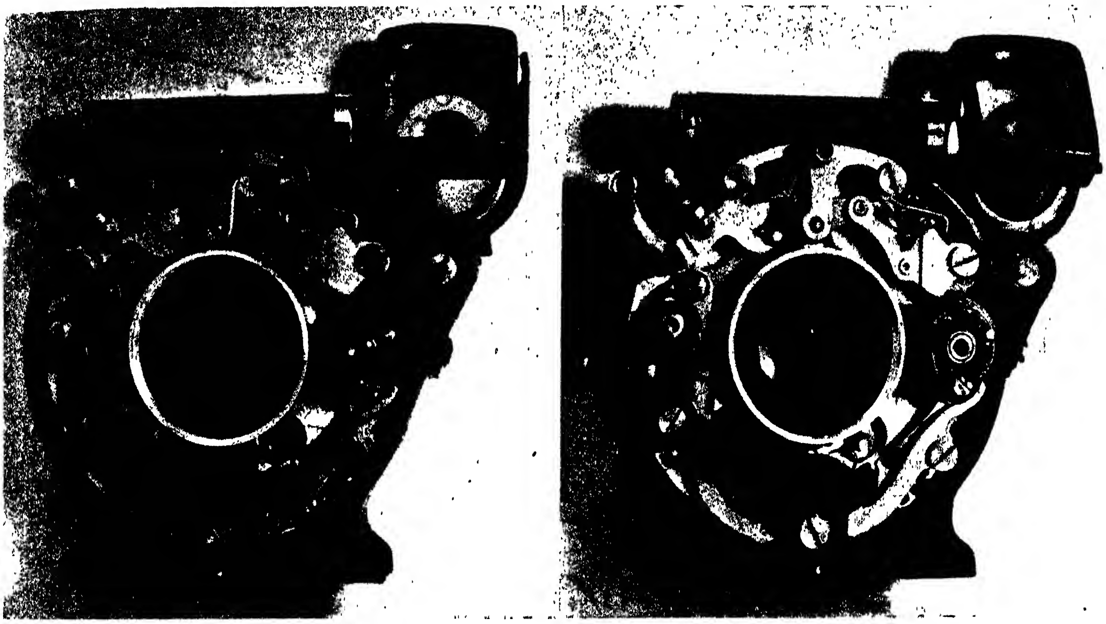


Fig. 2

half the distance of the paper. Otherwise, an object such as a pencil point may be held at this position, though distinctly at the risk of confusing the vision by drawing the focus away from the paper. Three images will be seen, from the centre one of which the relief takes form. The knack is really quite easy to acquire, and, once found, can be repeated at any future time without difficulty.

THE VALVE FILAMENT AT CONSTANT VOLTAGE.

By E. H. W. BANNER, M.Sc., A.M.I.E.E., A.Inst.P.

(*Continued from p.* 324)

Fig. 5 shows the general curve for the tests in this Section. The figures illustrate Test 15, but the shape of curves is generally similar to those for other valves and other values of resistance of potential divider. The ordinates are placed so that the values of E_f and I_{f0} corresponding to no emission are at the same point.

Theoretically, the family of curves of I_e with position of slider is as shown in Fig. 6. The difference in the emission with the slider at the two ends should be that corresponding to a difference of anode voltage of E_f volts, and the curve given in Fig. 5 agrees well with this. Other valves gave similar agreements, with a few exceptions.

This Section may be summarized as follows:

The circuit shown in Fig. 4 holds for all the valves tested, under the following variations of conditions:

Rheostat and ammeter (if used) in either lead.
Any anode voltage.
Any filament voltage.
Any resistance of potential divider.
Any voltage of filament battery.

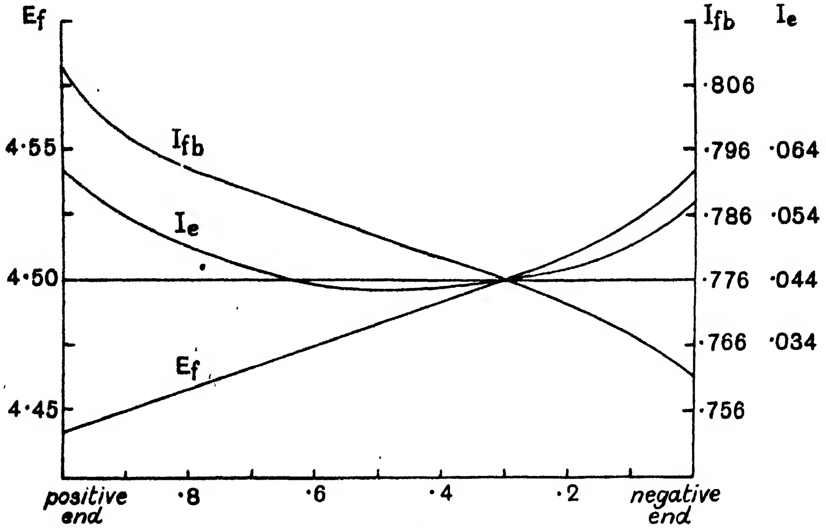


Fig. 5

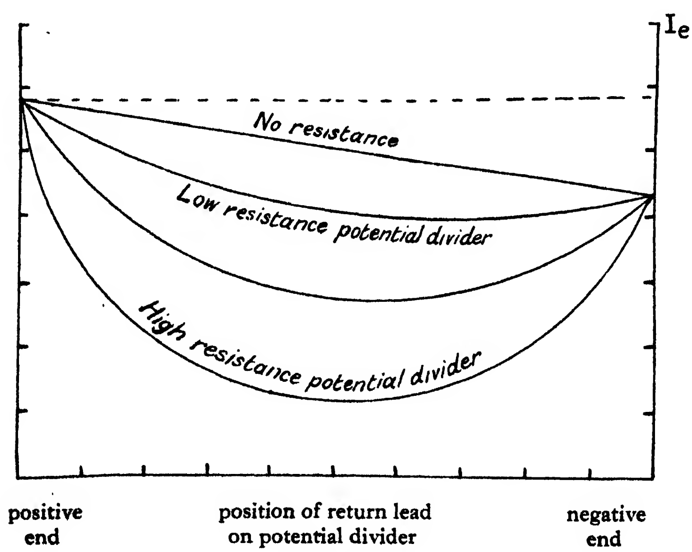


Fig. 6

The actual ratio depends on the particular valve, varying from ·3 to ·17, but the ratio for any valve is constant under these conditions.

A further test was performed with the circuit of Fig. 4, the resistance being fixed at

700 Ω and 300 Ω for the positive and negative ends respectively. Milliammeters were included in the leads from the potential divider and the following readings were taken.

Test 17. 12 *volt battery. Rheostat and ammeter in positive lead.*

E_f	I_{fb}		I_e	I +end	I −end
4·50	·845			·0045	·0045 reversed
4·50	·845	20	·0055	·0077	−·0032
4·50	·845	40	·0155	·0133	·0165
4·50	·845	60	·0255	·0195	·0312
4·50	·845	80	·0355	·0256	·0443
4·50	·845	100	·0418	·0295	·0520
4·50	·845	120	·0440	·0310	·0550
4·50	·845	140	·0455	·0316	·057
4·50	·845	160	·0465	·0320	·059
4·50	·845	180	·0470	·0326	·060
4·50	·845	200	·0480	·0331	·062

The proportion of current carried by the negative end of the potential divider increases as the emission increases until it is greater than the emission current, and at saturation the current in this circuit is approximately twice that in the positive end.

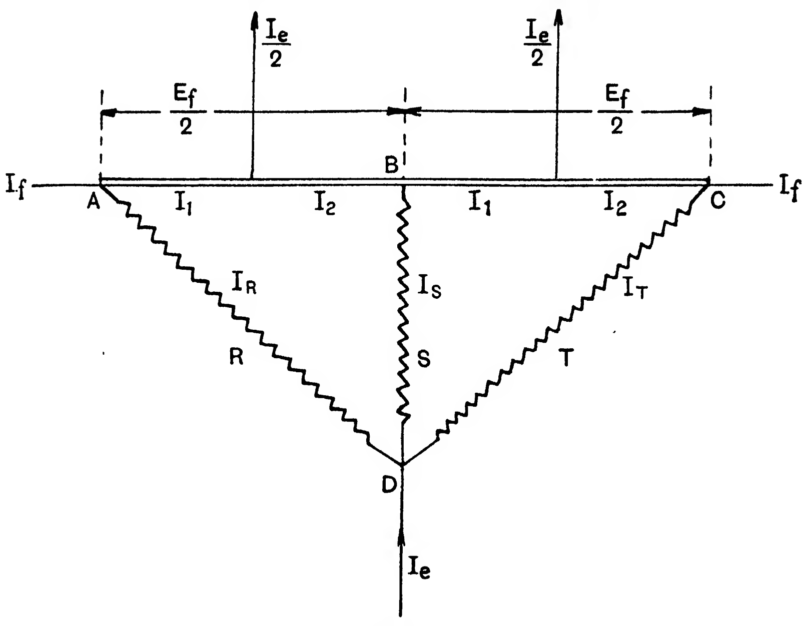


Fig. 7

After the completion of the experimental work a network which is a modification of one due to Round* was brought to the notice of the author.

This network consists of three resistances connecting the return to each end and to the centre—which must be available—of the filament.

Instead of the temperature gradient being a single slope from negative end to positive it consists of two slopes, the peak of each being half that of the previous case.

In this way the uneven filament heating should be halved. This circuit is used in practice on large rectifiers, for example at Daventry.

Considering Fig. 7, a filament is shown extending from A to C. The anode circuit return is fed in at D, and here three resistances R, S and T connect D to the filament.

* "Improvement in Valves used for Wireless Transmission," Patent Specification 154,982 of 1919.

Assuming we have equal emissions from the centres of the two halves of the filament, each of $\frac{I_e}{2}$, a solution of the network will give the ratios of the resistances required. This may be shown to be $R = T = 2S$, and that

$$I_S = \frac{I_e}{2} \text{ and } I_R = I_T = \frac{I_e}{4}.$$

For verification a valve having two filaments was used for a test, the two filaments being in series so that the mid-point was available. Milliammeters were connected in each network arm.

Regarding the currents in the network, I_R has its portion of I_e in the same direction as its steady battery current, and so increases continuously. I_S and I_T have their emission current reversed from their steady current.

At 7·5 volts the emission current balanced the steady current for this particular valve and network. After that the currents I_S and I_T continued to increase. R, S and T had been set at their values, found mathematically, namely $R = T = 2S$, and regarding I_R, I_S and I_T it is seen that

$$I_S = \frac{I_e}{2}$$

is correct at saturation only.

$$I_R = I_T.$$

This also is only approached at saturation, but at $E_a = 100$ volts, I_R is still appreciably greater than I_T,

$$\frac{I_S}{2} = I_R = I_T = \frac{I_e}{4}.$$

I_T is very nearly equal to $\frac{I_S}{2}$ at all emissions, but the other conditions are only approached as the filament becomes saturated. Finally, with this network the filament voltage, and the battery current, do not remain unchanged between emitting and non-emitting, as is the case for the circuit described previously.

The increase of I_f when the filament emits will be seen to be approximately $\frac{I_e}{4}$. From the above Fig. 8 is drawn. This shows the lines of current flow, considering the circuit discussed, where the centres of emission are concentrated in the points shown. The full line is I_f, which is constant. I_e is shown by four thin lines, each $\frac{I_e}{4}$, and it is drawn so that $\frac{I_e}{4}$ is added to the normal I_f.

It is then maintained that this portion of the emission current which is fed in at one end of the filament travels around the filament supply circuit and enters the filament at the other end from which it originally joined.

An inspection of Fig. 8 shows that with this network the current shown by the filament battery or transformer ammeter is the normal filament current plus a quarter of the emission current. In the equations I_f must be considered as the emitting value.

The equations given refer to instantaneous directions of currents, and as the network is symmetrical it is obvious that the network is equally applicable to alternating current filament supplies.

The above test did not show if the emission from each half of the filament was constant and so another test was performed using two LS5 valves in series, with a common anode supply through separate milliammeters.

The complete figures are not given for this test as they agree in proportion almost exactly with those of Test 17 using the single two-filament valve. The only added point is that of the separate emission currents.

These approached equality only as saturation was approached. At low anode voltages where the emission is space-charge limited the current through the instrument in the

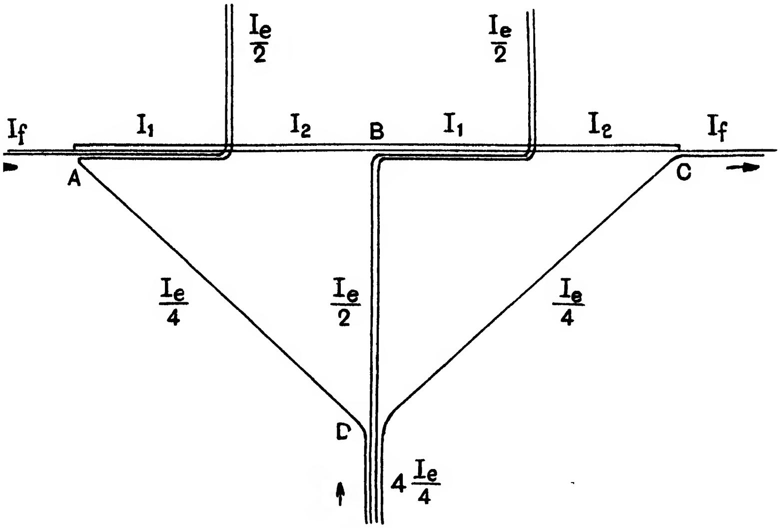


Fig. 8

circuit of the valve in the negative end was greater than that through the other. This and the previous network are not directly comparable. One provides a standard test circuit for precision work wherein a valve may be run at constant voltage independently of the emission, whilst the latter circuit is an attempt to obtain more uniform emission from a filament, with a view to conserving the life of the valve.

SECTION III

The preceding Section gave the impression that if the return lead were connected directly to the filament at the appropriate point the same result would occur, namely, that the filament voltage would be unaffected by emission. Accordingly, five DE3's were chosen and wired with their filaments in series and all anodes and grids in parallel. Connecting the return lead to the junction corresponding to the ratio ·2 found for this valve did not result in an unchanged reading.

Further trials showed the correct point to be between ·4 and ·6, and so one valve was removed, so that with four valves the point ·5 was obtainable. This proved correct, showing that the centre point of the filament system was the point to which the return lead should be connected (or alternatively to a point on a potential divider across the filament which was not ·5, but nearer the negative end of the filament).

As the four valves had different effective anode voltages it appeared that possibly the correct point for the return lead was not the centre of the filament of a single valve. Accordingly, a valve having two filaments was made. This was connected with the two filaments in series, the centre point being available for the return lead.

This case is not so straightforward as with the return lead to the network described in Section II. The reading of the voltmeter across the filament remains unaltered with different emissions, but the filament battery current changes.

Test 19 gives the results:

E_f	I_{fb}	E_a	I_e
11·63V	·455A	0	0
11·63	·458	20V	·035A
11·63	·459	40	·095
11·63	·453	60	·146
11·63	·448	80	·180
11·63	·444	100	·216

The filament voltage is low as it was run from a 12 volt battery and the drop is due to resistance of leads, instruments, etc. The filament battery current shows a rise at low emissions followed by a fall to less than normal at a high emission. This has not yet been explained.

It is the practice on some valve test-tables to readjust the filament voltage to normal after switching on the anode voltage. Section I showed that with the usual methods of connection the filament voltage is not the same when the valve is emitting as when the anode battery is disconnected, and so a test was made to find if this procedure is valid.

In the case of valves intended to be run without a rheostat the practice is obviously correct, as then the filament voltage is automatically maintained constant over a period of time with a fairly constant load.

Test 20. LS5 *valve.* 6 *volt battery, ammeter and rheostat in positive lead.*

$E_a = 50\,V$

	E_f	I_{fb}	I_e
Off	4·50	·784	0
On	4·54	·769	·0555
	4·50	·766	·0553 (E_f readjusted)
	4·68	·784	·0563 (I_f readjusted)

With neither of the readjustments are both the voltmeter and ammeter readings constant, and so the author concludes that the practice is not justifiable, except with valves needing no rheostat.

SECTION IV

Although small receiving valves rarely have their filaments run from an A.C. supply in use, it was considered desirable to find the altered conditions of the filament when emitting, and it was expected that, owing to the symmetry of such a circuit due to the sinusoidal wave, the case would be far easier to deal with than when run from a D.C. source.

To supply a filament from an A.C. source it is almost always necessary to use a transformer to obtain the required low voltage, and in such a circuit no rheostat would be used in the secondary or filament circuit, adjustments being made on the transformer primary only (Fig. 9).

The number of possible connections for the return lead then are as follows:

To either end of the filament.

To the centre of the filament.

To the centre of the transformer secondary, and

To the centre of a potential divider across the filament, and in the latter case the resistance of the potential divider may vary between wide limits.

To make the tests it was necessary to obtain a very steady source of A.C.

A transformer on Tirrill-regulated A.C. mains proved useless, as a fluctuation of the order of 1 per cent. is far too much to ensure readings of any degree of accuracy. It was finally accomplished by running a large motor-alternator set from a battery, with no other load on either the battery or the alternator. The frequency was 50 ~.

In order to check whether connecting the return lead to either end of a potential divider across the filament would give similar readings the following test was performed.

The LS5 was used with a potential divider of 2000 Ω resistance.

This test (no. 21) showed that there was a slight increase, when emitting, of E_f and I_f; with the return connected to various points on the potential divider I_e was less with the return at points between the filament ends; but this is expected, on account of the resistance being added to the anode circuit.

Test 22 was made with the two-filament valve, the return being to:

(*a*) one end of the filament,
(*b*) filament centre,
(*c*) centre of transformer secondary,
(*d*) centre of potential divider of 10,000 Ω,
(*e*) centre of potential divider of 1000 Ω,
(*f*) centre of potential divider of 100 Ω.

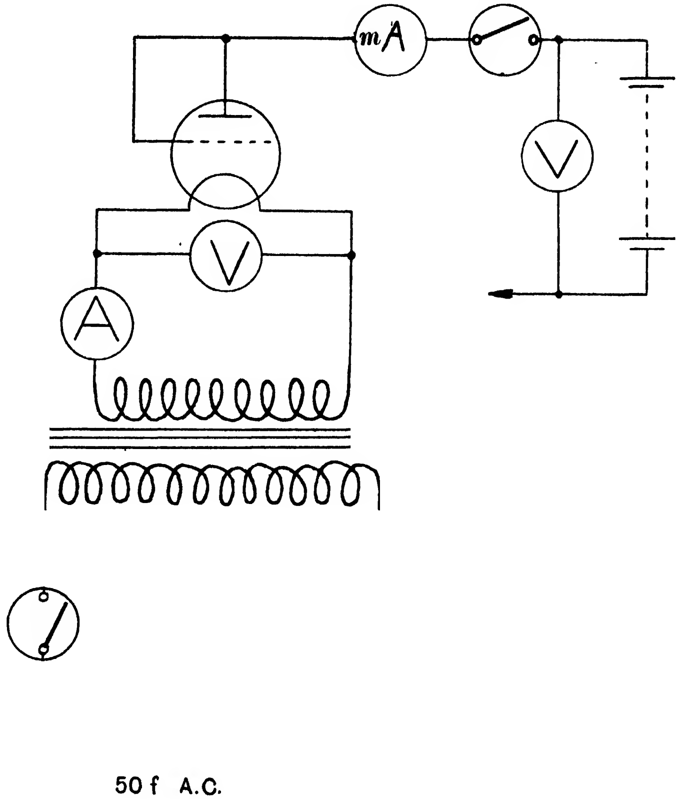


Fig. 9

Again these results confirmed the previous results of the slight increase in E_f and I_f when emitting, and further showed that the anode current is the same with the return connected to either end of the filament, to the centre of the filament or the filament transformer, but less if a potential divider is used, on account of the resistance being in the anode circuit, lowering the effective anode voltage.

CONCLUSION

The paper has shown that for standard tests on valves, except those valves intended for use without a rheostat, the ordinary methods of connection are not accurate. If, when a filament voltage is specified, the actual test circuit used is also stated, it is possible to compare results, but for accurate work the network described should be used.

As the position of the return lead is not constant for different valves a sliding or other adjustable potential divider should be used, the total resistance being of the order of 100 to 1000 Ω.

In inserting a valve and adjusting to about normal voltage the anode should be connected and the slider moved whilst switching on and off the anode voltage, until no alteration of filament voltmeter reading occurs.

For that type of the valve the test-table is then correctly set, and readings may be repeated easily, by maintaining this voltmeter reading constant by means of the filament rheostat.

A further small point is in specifying the filament voltage and current of valves with low consumption filaments. Either the voltmeter will read the drop across the ammeter as

well—this is not the correct connection—or the ammeter will read the voltmeter current, which with ·06 ampere filaments will not be negligible.

A means of overcoming this to a great extent is to include a "press-off" key in the voltmeter circuit. The steady filament current is read whilst the voltmeter key is pressed, the voltmeter then being out of circuit.

The author considers it would be informative if valve manufacturers or testing institutions could test large batches of similar valves run on similar conditions of load, but with D.C. and A.C. filament heating, to find how far the theoretical weakness of the negative end of a D.C. heated filament is true. Evidence of the prolongation of life when run on D.C. by periodically reversing the polarity is also wanted.

No published evidence seems to be available on these points, although it is believed that some large transmitting stations adopt the expedient of reversing the filament polarity daily.

Finally, thanks are due to Messrs B. S. Gossling, M.A. and A. C. Bartlett, M.A. for criticism and suggestions whilst the work was in progress.

APPENDIX

Particulars of Valves used

No.	Type	Bright or dull	Nature of filament	Rated E_f V	Rated I_f A	Hot filament resistance Ω	Shape of filament	Filament, length mm	Filament, diameter mm	$\frac{\text{length}}{\text{diameter}}$	Rated E_a V	End of tests maximum emission $E_a = 50\ V$ A	Rated impedance Ω	Rated m
1	R5V	Bright	Tungsten, plain	5·0	·7	7·15	Λ	34	·06	567	30–100	·0045	30,000	9
2	R	Bright	Tungsten, plain. Alcohol getter	4·0	·7	5·72	I	23·5	·06	392	30–100	·0088	40,000	9
3	LS5	Bright	Tungsten, thoriated	4·5	·8	5·63	Λ	60	·089	675	60–400	·056	6,000	5
4	DER	Dull	Tungsten, thoriated	1·8	·35	5·15	I	23	·06	284	30–80	·0048	32,000	9
5	DE5	Dull	Tungsten, thoriated. Magnesium getter	5–6	·25	20	Λ	28	·04	700	20–120	·027	8,000	7
6	DE8.LF	Dull	Gallium. Magnesium getter	5·6–6	·12	46·7	Λ	23	·026	885	20–100	·0195	8,000	7
7	DE3	Dull	Tungsten, thoriated. Magnesium getter	2·8	·06	46·7	I	17·5	·016	1100	20–80	·0039	22,000	7
8	Diode (special)	Dull	Tungsten, thoriated	15·0	·06	250	Λ	80	·016	5000	50–100	·0083	—	—
9	Two-filament (special)	Bright	Tungsten. Magnesium getter	6–6	·44	27·3	ΛΛ	—	·056	—	200	—	—	—
10	ORA (Mullard)	Bright	Tungsten, plain. Phosphorus getter	4·0	·67	5·98	I	23·5	·06	392	30–90	—	30,000	8·5
11	Dutch	Bright	Tungsten, plain	4·0	·5	8·0	I	23·5	·06	392	30–100	—	—	—

NEW INSTRUMENTS

THE CAMBRIDGE MAGNETIC BRIDGE PERMEAMETER

THE Cambridge Instrument Company have sent us an advance proof of their Leaflet No. 171, dealing with a new magnetic bridge permeameter developed from the design of Dr Edward Hughes. This instrument is of the bar and yoke type, and utilizes the principle of eliminating joints by bringing two portions of the test specimen to equal magnetic potential, as mentioned in Dr Drysdale's lecture to the Physical Society on p. 296 of the June number of the *Journal*.

As will be seen from the illustration (Fig. 1) and diagram (Fig. 2), the test specimen and yoke are provided with five windings. The central magnetizing coil U provides the

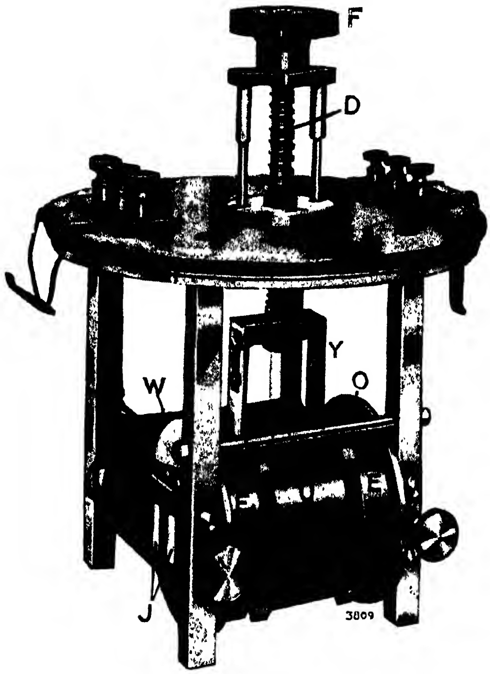
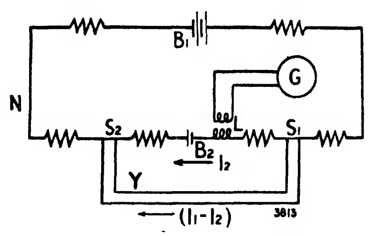


Fig. 1. The Bridge Unit



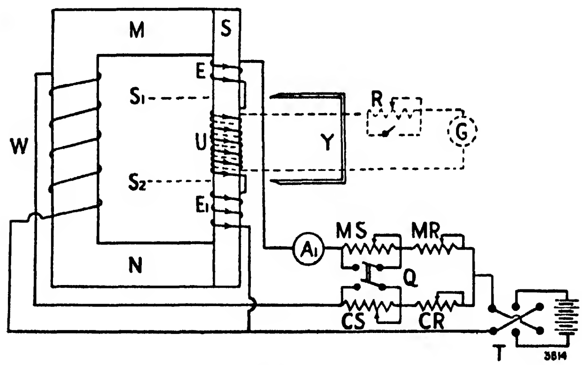


Fig. 2

magnetizing force required to overcome the reluctance of the specimen S; two supplementary coils E and E_1 maintain an even distribution of flux; and the winding W of the main yoke overcomes the reluctance of the ends and joints. The coils E, E_1 and U are connected in series, and this combination, with the necessary regulating resistances, is supplied from a battery and reversing switch which also supplies current to the coil W. The two currents can be independently regulated, the value of the current through coil U being shown on an ammeter. A search coil, shown by dotted lines, is wound over the central portion of the specimen, and can be connected to a galvanometer or fluxmeter.

The distance between the prongs of the test yoke Y determines the effective length of the specimen under test. This yoke is mounted on a spindle, with a spring and handle, so that its points can be pressed into contact with the specimen and suddenly released. If the two points are at the same magnetic potential, no flux will be shunted by the yoke Y when it is pressed into contact, and there will consequently be no deflection on the galvanometer when it is suddenly removed. In making a test, therefore, the current to give the

required magnetizing force is passed through the coils E, E_1 and U, and the auxiliary current through the coil W is regulated by the rheostats CS and CR until no deflection is obtained on bringing Y into contact or releasing it. The magnetizing force in the specimen will then be

$$\frac{4\pi}{10} \times \text{(ampere turns per cm. length of specimen)}.$$

In the instrument the number of turns is such that $H = 100I$, and the value of the flux is then given in the ordinary way by reversing the whole of the current and observing the throw on G. In order to eliminate any possible error by residual magnetization of the yoke Y it can be rotated end for end by the knob F (Fig. 1).

The whole of the yoke, specimen, and coils are enclosed in a tank, so that when values of H higher than 400 gauss are required, this tank may be filled with oil, and values of H up to 1000 can be employed.

Fig. 3 shows the hysteresis loop for a 35 per cent. cobalt steel specimen, determined with this apparatus, employing the ordinary Evershed method. The apparatus will deal with

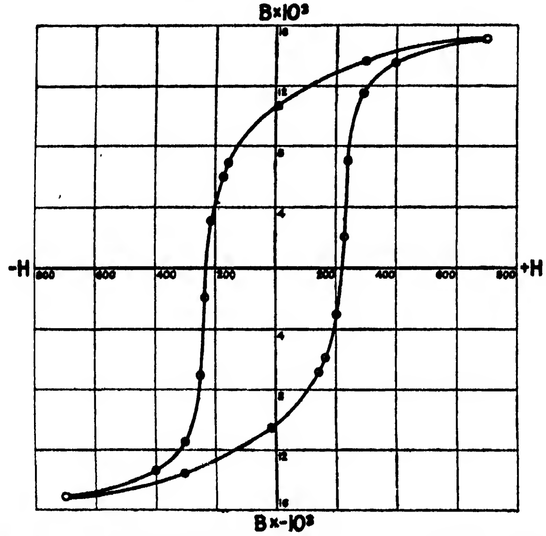


Fig. 3. Hysteresis Loop for 35 per cent. Cobalt Steel

rectangular or round specimens, either solid or laminated, 4½ inches long, with a maximum section of ¾ inch square, but may be used for smaller sections, provided they are sufficiently rigid. Specimens of greater length may also be tested.

BRITISH INSTRUMENT-MAKING LATHES

In view of the great difficulty which has been experienced in obtaining machine tools suitable for accurate instrument making from British sources, we are very pleased to see that Messrs Holbrook and Sons, of 44/46 Martin Street, Stratford, E. 15, have recently put on the market a 4″ precision bench lathe which appears to compare very favourably both for convenience and accuracy with any lathe of a similar type constructed on the Continent or in America. In the hope that this will be of interest to British scientific instrument makers, we have asked Messrs Holbrook to furnish particulars and illustrations of this lathe, and the following description has been sent in by them.

We are able to testify from personal experience as to the excellent workmanship, convenience, and accuracy of this form of lathe, and its cost compares favourably with similar tools of foreign make. A 4½″ lathe on similar lines has also been introduced by Messrs Holbrook, and is described below.

4-INCH PRECISION BENCH LATHE

One of the latest developments of Messrs Holbrook and Sons, Stratford, is a 4-inch precision bench lathe, which was designed mainly to meet the requirements of the Admiralty

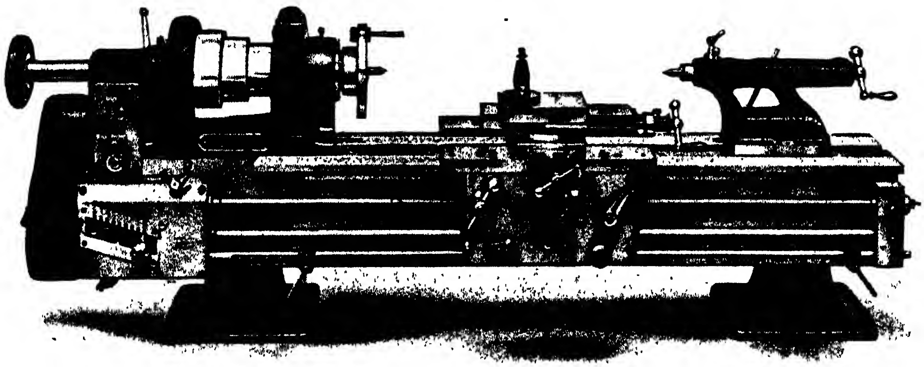


Fig. 1. No. 8 B Precision Bench Lathe

Research Laboratory, Teddington. The machine is especially suitable for intricate and instrument work, where a high degree of accuracy is required, and where quality is the main factor. An illustration of the lathe appears in Fig. 1.

The general dimensions are as follows:

Swing over bed	8 inches	Swing over saddle	5 inches
Take between centres	20 ,,	Length of bed	45 ,,

The fast headstock, which is back-geared, gives 12 spindle speeds (through a two-speed countershaft) ranging from 43 to 1340. The spindle, which is hardened, ground, and lapped, runs in hardened, tool-steel bearings. The front bearing is a double cone, with angles of 3 degrees and 45 degrees. Trouble from changes in the length of the spindle, due to temperature variation, is avoided by taking up all the end motion of the spindle on the front bearing. All parts are thoroughly protected from dust. The flange of the front gear wheel is indexed with 60 holes (giving sub-divisions, 2, 3, 4, 5, 6, 10, 12, 15, 20, 30 and 60). Both headstocks are clamped to the bed by means of eccentrics.

Great care has been taken with the design of the screw-cutting mechanism. It will be noticed that, although the lathe is fitted with a quick change gearbox, the number of gears actually used for screw-cutting is reduced to a minimum, the leadscrew being clutched direct on to the cone gear shaft. Furthermore, no bevel gears are used in the reversing mechanism, the desired motion being obtained through large straight tooth gears. The leadscrew itself is corrected on a special machine, from a master screw, which was tested and finally re-cut by the National Physical Laboratory and found to be accurate to within ·00001″ per foot.

The quick change gearbox is arranged to give 27 changes of threads, ranging from 12 to 80, including all Whitworth and B.S.F. threads. A chart is supplied, with instructions for cutting special threads—with the use of extra change gears. Metric pitches, ranging from ·3 to 4·0 mm., and B.A. pitches from Nos. 0 to 11 inclusive, can be obtained, with translating gears, as shown on the chart supplied. The gearbox gives also 27 changes of surfacing and sliding feeds, from 60 to 400 feeds per inch.

The slide rest can be furnished with the ordinary pillar type tool-box, for rectangular section tools, or with the spring-collet type (with eccentric adjustment) to take round tools. The maximum travel of the top slide is 5 inches. The screws are provided with large micrometer dials, graduated to ·001 of an inch.

The surfacing and sliding feeds (which are engaged by means of friction cones) are interlocked with the screw-cutting, so that neither feed can be put in whilst the screw-cutting mechanism is being used, and vice versa. A chasing dial, mounted in the apron, enables the operator to cut odd pitches without any difficulty. All the gearing in the apron runs in oil. Automatic stops for right and left hand screw-cutting are fitted with micrometer adjustment. The loose headstock barrel has a total travel of $3\frac{1}{2}''$, and is graduated to read in inches and sixteenths.

Drawback collets are furnished as standard equipment, and take bright rods up to $\frac{5}{8}''$ diameter. The standard equipment includes a two-speed ball bearing countershaft, three point steady, follow steady, hand rest, collet stand, and the necessary spanners. The lathe can be supplied with mahogany bench and self-contained countershaft. A large range of attachments can be fitted. The taper turning attachment, which is bolted to the back of the bed, allows tapers up to 4″ per foot on diameter, and 8″ long to be turned, and is graduated to read degrees and inches per foot.

Other attachments include a grinding head, for internal and external grinding, with a ball-bearing grinding countershaft, slotted or plain faceplates, ring chucks, internal and external, and spherical grinding attachment (for grinding ball-faces).

The $4\frac{1}{2}$-inch Lathe

The firm is also making a similar lathe, larger (Fig. 2), but not as a bench lathe. This particular precision lathe is of $4\frac{1}{2}''$ centre. It has a collet range up to 1″ diameter. The lathe

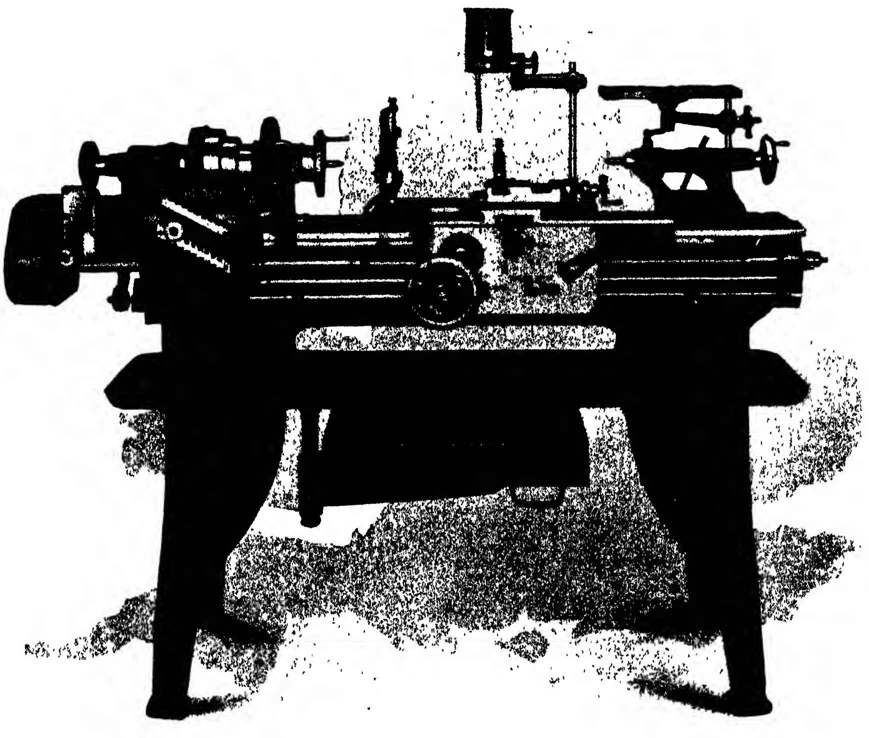


Fig. 2. No. 9 Precision Lathe

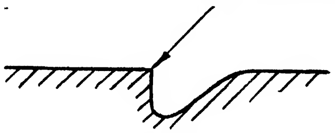
also has 27 direct changes, without altering the position of the gears which drive the quick change gearbox. It is mounted on standards and has an oil pan cast around the bed. The machine is heavier than the 8 B lathe, but has all its refinements.

LABORATORY AND WORKSHOP NOTES

BLANKING THIN METAL

It is difficult to secure clean blanks when punching very thin sheet metal with ordinary press tools, because, when the thickness of the metal is of the same order as the clearance between the punch and die, the edges of the blank are drawn over and tear raggedly, instead of shearing cleanly. The following method was devised here many years ago for blanking out leaves for iris diaphragms and for similar jobs, and has been found very satisfactory in operation.

Iris leaves are cut from metal $1\frac{1}{2}$ to 5 thousandths thick. They are blanked and pierced with two holes about ·03 inch diameter at one operation, and it is essential that the blanks should be of a very high quality, both as regards accuracy and finish. Instead of a die of the conventional type, a plain pad of rubber or leather is employed. The punch "immerses" the sheet metal in the pad, which flows closely around the sharp edges of the punch, and tears the blank out cleanly. To get the best results, the punch may be made by engraving the outline of the blank on a suitable block of steel. The working depth of the punch is not very great; it is sufficient to cut the groove about $\frac{1}{32}$ inch to $\frac{1}{16}$ inch deep. Its cross-section should be as indicated in the sketch, the blank being defined by the square edge.



Punch for blanking thin material. Cross-section of groove

If it is desired to pierce holes in the blank, corresponding holes should be drilled in the punch. To allow the piercings to escape, these holes should be drilled clear through the punch, and may be enlarged behind the working face. Such a punch can be cut very cheaply on a pantograph engraving machine, using as a master a dummy blank cut in celluloid, say ten times full size.

This style of construction has the advantage in use that deformation of the metal is limited to the groove, the rubber being supported by the punch everywhere else. The unsupported pressure over the groove draws the metal down over the rounded edge and tears it neatly along the square corner. As the sheet of material is pressed firmly against the face of the punch by the elastic pad, the whole face, and not merely the edges of the punch, will be operative in shaping the blank. For this reason a high quality finish on the face of the punch is necessary, and any marks, centre pops and the like, should be carefully ground out, or they will be transferred to the blank.

THE TAYLOR-HOBSON RESEARCH LABORATORY.

LEICESTER.

AN IMPROVED BRIDGE KEY. By E. H. W. BANNER, M.Sc., A.M.I.E.E., A.Inst.P.

A Wheatstone bridge key is described and illustrated which completely controls the battery and galvanometer circuits for ordinary resistance measurements.

The usual equipment for a bridge includes a battery key, galvanometer key, galvanometer shorting key (if a moving-coil galvanometer is used) and a variable galvanometer

shunt for protection of the galvanometer. All these are necessary for rapid working, but the shunt box need not be an accurately calibrated universal shunt such as is often used. The test being a null one, accuracy of the shunts is of no importance, and an expensive universal shunt is not essential.

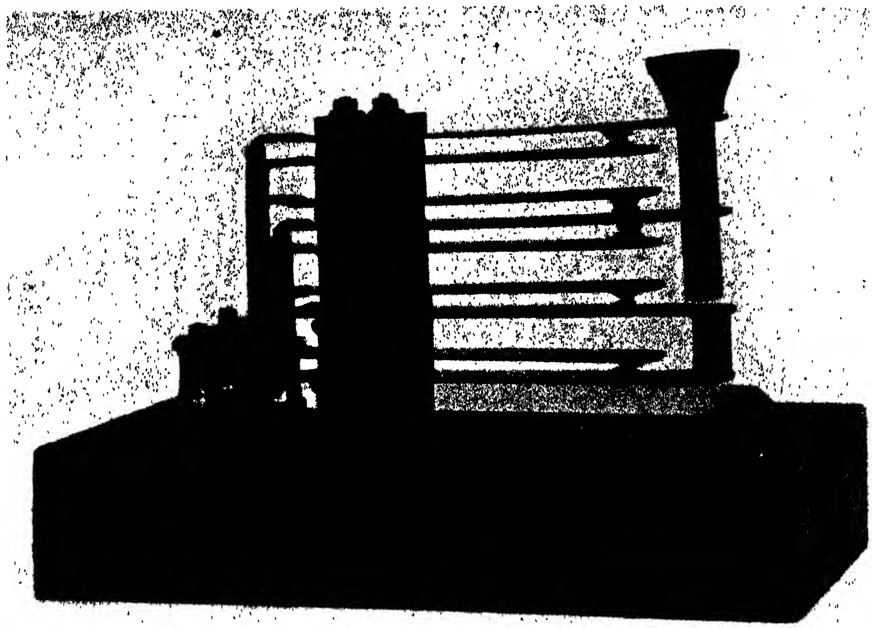


Fig. 1. An improved form of bridge key

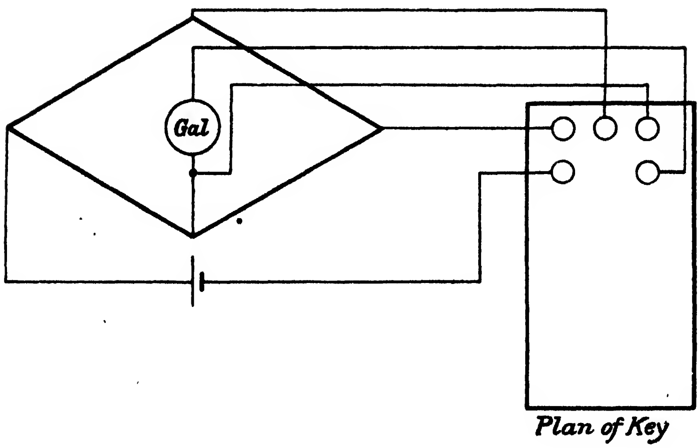


Fig. 2

The key described, of which Fig. 1 gives a general view, performs all the above functions, and in their correct sequence. With the knob up, the battery circuit is broken, the galvanometer shunted with two shunts, and shorted. Depressing the key first closes the battery circuit; next the galvanometer short circuit is removed, the two shunts remaining connected; next the galvanometer circuit is made, and as both shunts are in circuit a minimum current passes through the galvanometer. When the bridge is adjusted to an approximate balance,

further depression of the knob cuts out the low resistance shunt, so that further balancing is required. Finally the knob is fully depressed and the galvanometer connected directly in circuit. A final balance may then be obtained.

In the key made and described the shunts are of approximately 11 ohms and 100 ohms respectively. The galvanometer in general use has a resistance of about 1000 ohms, so that with both shunts in, for minimum sensitivity, for rough balance the shunt is 10 ohms, and the multiplying power 100. With the 100 ohm shunt only the multiplying power is 10.

For other galvanometer resistances the shunts may be altered, but unless the resistance is very low it is quite unnecessary. The shunts are not accurately adjusted as this also is unnecessary. Fig. 2 shows the connection of the bridge network to the five key terminals.

CONTEMPORARY PUBLICATIONS

Journal of the Optical Society of America and Review of Scientific Instruments

October, 1926. J. A. Stratton discusses a common type of capacity bridge, together with the modifications necessary and the precautions to be taken for operation at frequencies of the order of 500,000 cycles per second. Fixed resistance ratio arms are employed, and phase angle correction is obtained either by variable resistors or by the insertion of variable inductors. A new quartz ultra-violet monochromator is described by Henry F. Kurtz. The instrument has been designed to give constancy of deviation and high light-gathering power. A modified Young prism system is employed and the quartz objectives are provided with aspherical surfaces.

C. W. van der Merwe shows that, for the transmission of speech, a specially constructed discharge tube containing a trace of a mixture of helium and neon gives better results than the "speaking arc." Richard M. Badger describes a new form of sputtering apparatus which has been found convenient for dealing with large mirrors (the dimensions given apply to mirrors of diameter up to 10 cm.). An instrument for determining the optic axes of large crystals of quartz is described by L. H. Dawson. John T. Norton and B. E. Warren show that the examination of radiographic negatives with a photographic densitometer enables the size of a discontinuity in the material to be determined with considerable precision. A simplified Pascal integraph is described by Paul Kirkpatrick, and a laboratory device for securing constant angular speed is described by the same author and M. C. Magarian.

November, 1926. J. W. Beams discusses a method of obtaining light flashes of uniform intensity and short duration by means of an electro-optical shutter which opens and closes abruptly. Perry A. Borden describes an accessory device for potentiometers, which has been found useful in checking the accuracy of wattmeters and in such work as the precise measurement of low resistance values. Paul Kirkpatrick shows how the galvanometer deflection obtained by a series of increasing oscillations, when a small potential is applied at properly timed intervals, may be used in the measurement of currents or potentials too small for readable steady deflections. Improved illumination in the process of enlarging negatives is obtained by the use of a condenser, described by L. V. Foster, in which the lenses each have one spherical and one paraboloidal surface. For special purposes the lenses consist of glass shells filled with water.

December, 1926. A. W. Simon and D. H. Loughridge contribute a paper on the Wilson cloud expansion chamber. The chamber described contains a number of new features. James P. C. Southall discusses the form of the so-called "Punktal" lens patented and made

by Carl Zeiss. The results obtained should be of use to the manufacturers of spectacle lenses. An electromagnetic separator, designed for use in chemical and mineralogical laboratories, for the purpose of separating minerals for analysis, is described by Charles J. Ksanda. A description of a new continuous-indicating hygrometer is given by Arnold Romberg and L. W. Blau. The humidity is determined by balancing a column of atmospheric air against a column of air saturated with water vapour and observing the effect, on a suspended vane, of the difference of pressure due to the different densities. S. S. Makeown describes a high voltage direct current generator, and an account of an improved electric flow meter is given by Thomas R. Harrison.

January, 1927. Maurice L. Huggins suggests a modification of the gnomonic ruler described by Wyckoff for use with Laue photographs. Warren W. Nicholas discusses the accuracy attainable with an X-ray spectrometer with which wave-lengths are read directly on an ordinary micrometer screw, and describes several features of construction of such an apparatus. The results of an investigation on the ballistic characteristics of the photoelectric cell are given in a paper by F. E. Null. A new type of aspirator of high efficiency is described by E. L. Harrington.

February, 1927. Simple instruments for direct readings of solar radiation intensity from sun and sky are described by Ladislaus Gorczyński. A description of a new form of illuminator for use in metallographic microscopy is given by Lewis E. Jewell. With the introduction of the new sensitising dye "Neocyanine" it has become possible to photograph spectra without difficulty as far as 900 $m\mu$. A. L. Schoen gives particulars of a photographic method (making use of plates sensitised with this dye) of spectro-photometry in the red and infra-red. G. G. Kretchmar describes a glass water still, which consists of a Pyrex flask attached to a condenser of the same material in such a way that the water level is maintained during operation. The heater is a 600-watt element made of nickel-chromium and is directly immersed in the water.

March, 1927. A. H. Bennett contributes a paper on the distortion of some typical photographic objectives both for infinite and finite object distances. In another paper the same author and I. C. Gardner show that in many cases distortion can be compensated by a plane parallel plate used as an additional component of the lens, the effect of the plate being generally not detrimental to the correction of the other aberrations. Joseph Kaplan discusses the sensitivity of the Case "Thalofide" cell between 0·5 and 1·2 μ, and suggests several possible uses for the cell in spectroscopy. Two methods of measuring potentials of the order of 100,000 volts, making use of ordinary laboratory instruments, are described by Ross Gunn. A new type of resistance with an "effective zero-temperature coefficient" is also described. Elias Klein and Glenn F. Rouse discuss a number of methods of exciting and calibrating tuning-forks.

April, 1927. Preston B. Carwile describes a direct current potential transformer which operates electrostatically and manipulates the connections of a direct current source and n condensers in such a way that the initial potential difference is multiplied by the factor 2^n. Lauriston Taylor gives the results of a comparison of three spectro-photometric methods using (1) the Lummer-Brodhun spectrophotometer, (2) a spectrograph in which the two spectra were photographed simultaneously by means of a divided slit, and (3) a photo-electric spectrophotometer. An infra-red spectrometer of large aperture ($f/2$) is described by A. H. Pfund, and a polarization photometer eyepiece by F. E. Wright. A. L. Fitch discusses some of the uses of a vacuum tube potentiometer. A simple mercury arc lamp for laboratory use is described by D. S. Ainslie. A paper on the energy distribution and efficiency of the quartz mercury arc as functions of arc voltage, current density, and tube diameter is contributed by Donald C. Stockbarger.

May, 1927. A résumé of previous work in the field of magneto-striction is given by S. R. Williams. The use of a calibrated thermal resistance plate for measuring heat flow is discussed by Carl G. F. Zobel. An apparatus for selecting atoms of particular velocities from atomic and molecular rays is described by J. Tykocinski-Tykociner. The theory of the action is outlined, and the characteristics of expected spectrum-like images are discussed. C. B. Crofutt shows how exceptionally good dust figures are obtained when the metal rod in Kundt's tube is replaced by the loud speaker of the vacuum tube oscillator. The development of a small and inexpensive photometer for determining light intensities and photographic exposures is described by F. H. Norton.

June, 1927. Crandall Z. Rosecrans describes an automatic instrument for recording the percentage of CO_2 in air supplied to greenhouses. The application of the thermal conductivity method of gas analysis is described, and several new features are discussed. Frederick G. Keyes and Jane Dewey contribute a paper on an experimental study of the piston pressure gauge to 600 atmospheres. The optical system of the oscillograph and similar recording instruments is discussed by Arthur C. Hardy. A simple automatic mercury still is described by Howard L. Bronson.

CORRESPONDENCE

STANDARDS OF INDUCTANCE

In Dr Drysdale's interesting article in your June issue (on the Design and Construction of Electrical Instruments) he remarks that the variable standard of inductance of Professors Ayrton and Perry "was an instrument of very high precision which has hardly been surpassed up to this day." This statement seems to me to exaggerate very considerably the accuracy of the old standard, as will be seen from the following description. The A. and P. standard, of range 5 to 50 mH, had a scale of only about 165° in extent, and accordingly the accuracy of reading, particularly at the lower values, could not be great. The error due to frequency was about − 3·2 per cent. at 2000 cycles per second.

Let me contrast with this the long-range inductometer which I introduced nearly 20 years ago. The range (from 0 to 10 mH) extends virtually to 16,000°, being readable to 1 in 100,000 at the maximum and to 1 in 10,000 at $\frac{1}{10}$ of maximum, the proportionality over a great part of this long range being accurate to 1 or 2 in 10,000. In the original models the error due to frequency was about 0·4 per cent. at 2000 cycles per second.

ALBERT CAMPBELL.

CULMORA, GIRTON ROAD, CAMBRIDGE.

I am sorry that Mr Campbell should have thought that my eulogy of the Ayrton and Perry inductometer implied any want of appreciation of his own most excellent inductance standard, to which I immediately afterwards referred as "having higher accuracy of construction and very long range." But Professors Ayrton and Perry's instrument was a variable standard of *self* inductance, whereas Mr Campbell's was one of *mutual* inductance, which makes a considerable difference. It is quite true that inductance measurement can generally be made equally easily with a variable mutual inductance standard, which lends itself to multiple ranges by stranding the fixed coils and adding fixed ratios, and thus gives a much higher range, but it is extremely difficult to produce a variable self inductance with a greater range than 10 to 1, and it was a great achievement of Professors Ayrton and Perry to obtain this in the early days. I have myself extended the range of variable self inductance standards by making the fixed and moving coils of two strands, which can be connected in series or parallel, giving a range of about 40 to 1, and by adding coils of fixed value so

disposed as practically to eliminate interference between them; but it is not easy to see how stranding can be carried out to a much greater degree in a moving coil.

Mr Campbell's remarks concerning the frequency variation are quite justified, but again it is much more difficult to keep this error down in a self inductance standard in which the whole of the copper windings are included in the bridge arm, and consequently should have as low a resistance as possible, than in a mutual inductance in which only one part of the winding need be so included.

C. V. DRYSDALE.

MULTI-RANGE LABORATORY VOLTMETERS

ALTHOUGH a certain amount of standardization of indicating instruments has been done by the B.E.S.A., I believe there is still a line of development which is, as far as I am aware, quite untouched. If it may be taken that multi-range voltmeters of any type but electrostatic are produced by series resistances, then laboratory voltmeters could be made considerably more useful if an unlimited number of ranges was available.

In general, the cost of a three or four range voltmeter is about twice that of a single range, and although a certain saving in first cost is effected, the ranges could be increased almost infinitely in a very simple manner, without the addition of instruments other than resistance boxes usually on hand in a laboratory or test-room.

The moving-coil voltmeter is, as usual, more versatile than other types, and an indicator having a resistance of 10 ohms and requiring 10 milliamperes is quite easy to produce; this range would be made as a unit. The resistance would be 100 ohms per volt and the scale ·1 volt. If 100 scale divisions are marked, numbered 0–1, any other range would be available with the addition of either resistance boxes or a Wheatstone bridge of any type; the accuracy of these resistances should be well within the limits of error of the instrument, and so accuracy would not be impaired.

Other instruments would have a smaller resistance per volt, and a 1 volt moving-iron instrument might not be suitable for more than, say, 100 volts, or the current consumption would be excessive. Resistances for use with these might have to be tested for accuracy at the relatively high current required.

If instrument makers would market such instruments I think laboratories and test-rooms would quickly realize the saving in cost and the wide choice of ranges at their disposal.

E. H. W. BANNER.

7 ROSSLYN CRESCENT, NORTH WEMBLEY.

DESIGN AND CONSTRUCTION OF ELECTRICAL INSTRUMENTS

I WISH to point out what appears to me to be a slip in the issue of *The Journal of Scientific Instruments* for June. On p. 294 the expression $R^2 = LK$ is given in connection with a type of A.C. potentiometer, or in standard notation $R^2 = LC$. Working out the condition to give a phase angle of 90° between the two branches I get $R^2 = L/C$, the correctness of which is supported by taking likely values for the components.

MARCUS G. SCROGGIE.

VENTON
19, ST MILDRED'S ROAD,
LEE, S.E. 12.

Mr Scroggie's criticism is quite correct, and the slip is regretted. The angle of lag ϕ in the inductive arm is given by $\tan\phi = \frac{L\omega}{R}$, and the angle of lead θ in the condenser arm by $\cot\theta = KR\omega$; so that for $\theta + \phi$ to be 90°, $\cot\theta = \tan\phi$, or $KR\omega = \frac{L\omega}{R}$, or $R^2 = \frac{L}{K}$, which is independent of the frequency.

C. V. DRYSDALE.

REVIEWS

Wireless Loud Speakers. By N. W. McLachlan, D.Sc., M.I.E.E., F.Inst.P. (*Wireless World.* Iliffe & Sons, Ltd. 139 pp.) Price 2*s*. 6*d*. net.

Few technical subjects are of greater popular interest at the present time than that of the construction of loud speakers to obtain the maximum volume and purity of tone, and in the little volume now before us Dr McLachlan, whose success as a designer of such instruments is well known, has produced a most useful compendium of theory, design, and practical construction, which will appeal both to those who have considerable or slight technical knowledge.

The subject bristles with difficulties, and it would be too much to say that the author has even pretended to give a complete theory or the rules for design, but he has contrived to marshal the salient points of theory in a lucid and readable form, and to blend practical and theoretical considerations and descriptions of the most generally used forms in a very happy manner. Few interested in the subject will read the book without great benefit, especially as it gives a popular and intelligible account of many acoustic methods which have hitherto been enshrouded in mathematical treatises like Lord Rayleigh's "Sound."

The book is divided into 14 chapters, the first of which deals with acoustic principles, including the questions of equality of tone, the sensitivity of the ear, the different frequencies and the effects of damping and resonance. Chapter 2 deals with the horn type loud speaker, and shows the effect of the forms of the mechanism of throat and horn upon the frequency distribution; while chapter 3 describes some of the actual forms of horn type loud speakers in use. Chapter 4 opens the subject of hornless or large diaphragm loud speakers, which is continued in chapters 5 and 6, dealing with the action of a diaphragm and its shape and size. In chapter 7 the effect of reflectors and of resonance and reflections in the room are dealt with, and in chapter 8 the distribution of energy from a diaphragm and the polar curves for different frequencies.

The driving mechanisms and diaphragms of loud speakers are considered in chapter 9, with the vector diagrams applying to them; and quasi-resonant types of loud speakers are described in chapters 10 and 11. Chapter 12 is devoted to amplifiers for operating loud speakers and gives a very good account of resistance-capacity, neutrodyne, and transformer amplifiers with their different characteristics; while chapter 13 gives instructions for the making of a loud speaker, and chapter 14 summarises the salient points of the whole subject.

We can warmly recommend this little volume to all who are interested in this fascinating and important subject.

C. V. D.

Communications from the Physical Laboratory of the University of Leiden. Commenced by H. Kamerlingh Onnes, continued by W. H. Keesom and W. J. de Haas. Nos. 173, 174, 176, 177, 178, 180, 181, 183, and Supplements 54, 56–59.

These communications consist for the most part of reprints of previously published papers describing researches carried out at the University of Leiden. Most of the original papers are in Dutch, but these have been translated into English for the present publications. In this way a large mass of important research work is made immediately available for English-speaking scientists. The range of subjects dealt with is fairly extended. As one would expect, however, nearly all the researches relate to the properties of matter at very low temperatures.

Nos. 174, 180, and 181 contain a group of papers by Onnes, Tuyn, Sizoo and others on the supra-conductive state, chiefly in connection with the magnetic disturbance of supra-conductivity. Of special interest is an account of an attempt to attain the supra-conductive state for an extended series of metals. Contrary to earlier anticipations, it appears that only a very limited number of metals show supra-conductivity, at least for the lowest temperature at present attainable, namely 1·5° K. A further group of papers by Vegard, Onnes, and Keesom deals with the luminescence of "gases in the solid state." The work of Vegard in applying such luminescence to the explanation of cosmic phenomena such as the aurora borealis is well known, and the present papers have a special interest for this reason alone. Supplement No. 58, by Onnes and Tuyn, bears the title "Data concerning the electrical resistance of elementary substances at temperatures below

− 80° C.," and contains the results which served as the basis for a chapter in the "International Critical Tables." This volume by itself forms an impressive monument to the industry and skill of the research workers in the Leiden Laboratory.

Professor Keesom, one of the present directors of the Laboratory, presents in Supplement No. 57 a short paper on "Prof. Dr H. Kamerlingh Onnes. His life-work, the founding of the Cryogenic Laboratory." This will be read with interest by all who have been connected in any way with low temperature work. W. S. S.

Theory of Vibrating Systems and Sound. By I. B. Crandall, Ph.D. (London: Macmillan and Co., Ltd. Pp. 272.) Price 20*s*. net.

In view of the growing importance of applied acoustics, a new book which brings the subject a little nearer up-to-date is welcome. Although little or no advance on the purely theoretical side has been made since the appearance of the classical treatises of Rayleigh and Lamb, there is much to be said regarding the technical advances in the science of vibrating systems and sound. In the present work the author deals with the subject as a special branch of analytical mechanics, the studies on which the book is based having formed the basis of a course of lectures to the technical staff of the Bell Telephone Laboratories and to students at the Massachusetts Institute of Technology. The treatment is essentially mathematical, free use being made of Rayleigh's theory as applied to special technical problems.

The first chapter, dealing with simple vibrating systems, includes the general theory of the vibration of a circular membrane (such as the telephone diaphragm), followed by consideration of the equivalent piston system as exemplified approximately in the condenser microphone. The second chapter deals more particularly with resonators and acoustic filters, special treatment being given to a resonator coupled to a diaphragm, and to the problem of a loaded string. In the case of the acoustic filters the electrical analogy is followed—assuming that for every electrical filter known there is an acoustic analogue, though all are not equally practicable.

Chapter three, which deals with the propagation of sound, includes, in addition to the general theory of wave propagation, the transmission of sound in tubes (including the resonance conditions) and the problem of the pulsating sphere as a sound generator. This chapter concludes with interesting observations on the reaction of the surrounding medium on a vibrating string, with particular reference to the vibrations of the string of an Einthoven galvanometer.

Radiation and transmission problems are dealt with in the next chapter, particular consideration being given to the theory of a piston in a semi-infinite wall, radiating high frequency waves (say at 50,000 cycles per sec.), as an example of which reference is made to a quartz piezo-electric oscillator tuned by means of "quarter-wave" iron slabs. The characteristics of horns, conical and exponential, are dealt with very fully in this section.

The last chapter is primarily concerned with architectural acoustics, involving the problems of reflection, absorption, and reverberation in closed spaces. The pioneer work of Sabine is emphasized. The book concludes with a useful appendix containing references to recent publications in applied acoustics, brief notes being attached to make these references more intelligible.

The volume cannot in any sense be regarded as a text-book of sound, but it certainly gives a very thorough treatment of those particular sections of applied acoustics which are touched upon. To those interested in such technical applications of acoustics, and possessing a moderate mathematical knowledge, the book should prove both interesting and instructive. A. B. W.

ERRATUM

In the paper on "A Versatile Inductometer Bridge" by Albert Campbell, M.A. (page 305, July issue, eighth line from bottom), the range of mutual inductance should read "−5 up to 152·5 μH."

JOURNAL OF SCIENTIFIC INSTRUMENTS

VOL. IV SEPTEMBER, 1927 No. 12

A NEW PHOTO-ELECTRIC DENSITY METER.

By F. C. TOY, D.Sc., F.INST.P. (Communication No. 63 from the British Photographic Research Association Laboratories.)

[*MS. received, 3rd April,* 1927.]

ABSTRACT. The selenium cell type of density meter, previously described in this *Journal*, suffers from two defects when densities greater than about 2 are being measured; it becomes slow in action, and rather insensitive. The former defect is due to the inherent "lag" of the selenium, and the latter to the small amount of light falling on the cell—a condition which also accentuates its slow action.

Without increasing the power of the light source, both of these defects have been eliminated in the machine now described by replacing the selenium cell by a gas filled photo-electric cell, and utilizing all the light which passes through the diffusing opals, instead of only a small fraction of it. This necessitates the construction of a special photo-electric cell having two windows at right angles to one another, but results in a very simple optical system. The photo-electric current is magnified by a valve method, so that a very robust, quick acting, dead-beat galvanometer may be used. The machine is coupled to an automatic curve tracer.

THIS instrument has been designed to replace the one previously described in this *Journal** for the measurement of the density of photographic negatives. Although the original machine has been found to be a great advance on the old and laborious visual methods, both as regards accuracy and speed of working, it has become necessary, because of the continually increasing output of negative material of which the densities are required, to speed up the measurements still more if possible. The old machine was fitted with a Thirring selenium cell, and although with this type of cell the characteristic "lag" of selenium is comparatively small when the amount of light falling on it is large, it becomes very large when the incident light is small, *i.e.* when measuring the higher densities. Actually for all measurements above a density of about 2, the lag becomes sufficient to make the rate of working decidedly less than at say 0·5, while at 3, the maximum density which can be measured, the instrument records too slowly. The low intensity of light falling on the cell at high densities is due, however, not only to the large value of the density, but also to the fact that only a small fraction of the light which passes through the diffusing opal is available for illuminating the selenium cell. This is illustrated in Fig. 1, where O represents the illuminated opal on which the negative to be measured is placed, and L the first collecting lens of the optical system which focusses this beam on the selenium. In the actual machine the distance OL is about 6 cm. and the diameter of the lens L, 1·8 cm., and if we assume for approximate purposes that the opal is a perfect diffuser it is easy to show that only about 3 per cent. of the emergent beam is collected by the lens L. This great loss of light, combined with the characteristic lag of selenium, are the chief faults of the original machine.

* *Journ. Scient. Instr.* 1 (1924) 362–365.

In the instrument now to be described both these faults have been completely eliminated, the first by placing the cell so that *practically all* the light transmitted by the opal is utilized, and the second by replacing the selenium by a potassium hydride photo-electric cell. Fig. 2 illustrates the new principle. The cell is placed with its window in contact with the opal diffuser, so that practically all the emergent beam must enter the cell, the negative to be

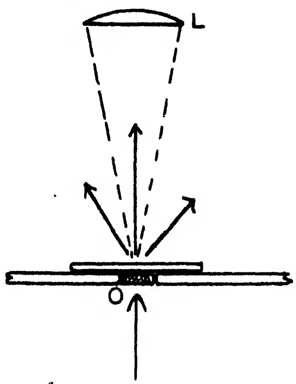


Fig. 1

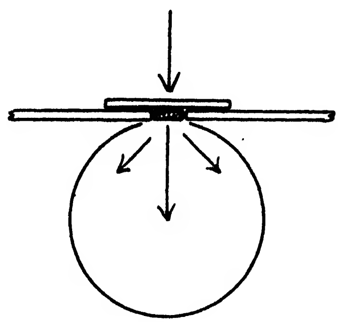


Fig. 2

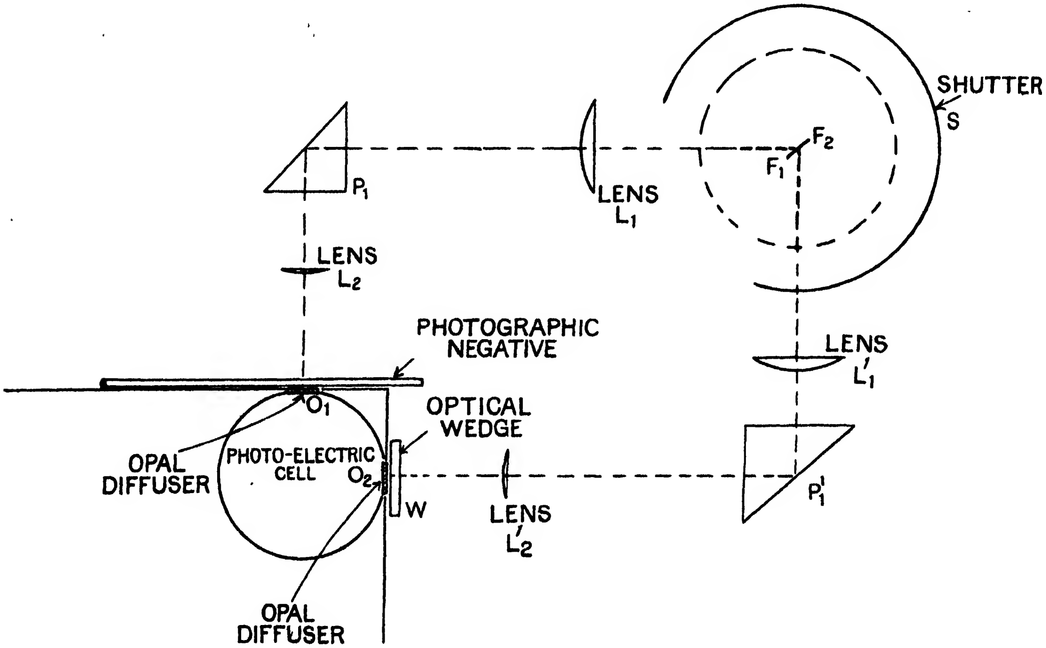


Fig. 3

measured now being on the same side of the opal as the light source. Since in this type of machine, which is, strictly speaking, a density comparator, the light entering the cell through the unknown density is compared with that through a standard optical wedge of which the density is known at every point, the difficulty arises that if the opal is placed close to the window, there is no room for the comparison beam to enter the cell, through the same window. This difficulty is surmounted by having another window at right angles to the first. Fig. 3 shows how simple is the optical system which can be adopted, using this two-window principle.

The light source is a 12 volt 2 ampère metal filament (gas filled) lamp, the filament of which, a straight spiral represented by F_1F_2, is inclined to, but is in the same plane as the two light beams, at right angles to one another, which are taken from the lamp. One beam is concentrated on the opal O_1 by means of the lenses L_1 and L_2 and the prism P_1, and the other on O_2 by a similar optical train. L_1 is placed so that all parts of the filament F_1F_2 are outside its focus, so that a slightly converging beam is reflected on to L_2 by means of P_1. An image of F_1F_2 is formed at L_2 (only the centre point of the filament is accurately focussed), while the latter forms a uniformly illuminated image of the lens aperture L_1 on O_1. The negative to be measured is placed in contact with O_1 and the optical wedge W is movable across O_2 in a direction perpendicular to the plane of the paper. In order that the cell may be illuminated by each beam only, acting alternately, a shutter, S, is placed round the lamp, and is so cut that one beam is cut out just as fast as the other is let in, when the shutter is rotated. Actually in the figure it is shown in one of its "end" positions, so that O_1 is fully illuminated by the beam through $L_1P_1L_2$, while O_2 is not illuminated at all. The shutter is simply a metal tube, out of which a section slightly larger than one quadrant has been cut, and a second similar tube sliding over the first and adjustable so that the two together give an exact quadrant.

Since the zero position of the optical wedge has quite an appreciable density, it is necessary, in order to get a zero balance, to cut down the light in the beam through the negative relative to that through the wedge. This can be done in either of two ways (*a*) by means of an iris diaphragm on the lens L_2, or (*b*) by slightly rotating the lamp holder so that the filament F_1F_2 is turned slightly more towards the standard comparison beam than towards the other.

The machine is designed specially for the measurement of the average density of fairly large patches of negative, such as circular patches 4 to 5 mm. in diameter. In order, however, to make the instrument as far as possible suitable for general purposes it is possible to vary very considerably the size of patch of negative being measured. This is carried out by having two adjustable stops close to the lens L_1. One consists of two straight jaws whose distance apart can be varied, while across these runs a narrow V-shaped slot, just as is used for controlling the length of a spectroscope slit. By suitable adjustment of these two stops, an extremely small patch of light can be passed through the negative to be measured, or alternatively a narrow slit of light of any length up to a maximum given by the diameter of the opal can be used for the measurement of spectral lines or of the distribution of density along the length of a continuous spectrum. By having a better quality lens L_2 than that used in the present machine, the density of quite fine spectral lines could be measured, provided they were not too dense. The instrument is not, however, designed primarily for fine spectral line work.

Since in this instrument the light passes down through the negative and opal and into the cell, the observer can only see the position of the negative, in relation to that of the opal, by means of light which is reflected from the opal back through the negative to the observer. As the density increases this light decreases, but at the same time the light reflected from the silver deposit itself increases. When the latter is large compared with the former the position of the negative can no longer be easily seen. If the machine is to be used largely for the measurement of characteristic curves, this difficulty is easily overcome, as in the present machine, by having a ruled scale on the table of the instrument, so that setting the edge of the negative against a certain line insures that the opal will be underneath the centre of a definite exposure "step." In other cases it is very easy and perfectly satisfactory to make a mark on the glass surface of the negative around the point it is required to measure.

The wedge used is an Ilford Neutral Optical Wedge having a gradation (*i.e.* increase of

density per unit length) of about 1 per inch. The movement which carries the wedge is connected mechanically to the vernier on the front of the machine, so that the density of the wedge at the opal O_2 can be read off for any position of the wedge. The photo-electric cell was specially constructed by Mr T. C. Keeley of the Clarendon Laboratory, Oxford, and has been found very satisfactory.

A few words must be said about the electrical circuit. Two possible methods of recording the current changes in the cell suggest themselves: Firstly there is the method, now so commonly used, of measuring, by means of an electrometer, the change in potential across a high resistance through which the photo-electric current leaks to earth, and secondly, some method of valve amplification. The most convenient type of electrometer to use in the first method is the Lindemann string electrometer, as used by Dobson* with his photometer. The objection to this is the necessity for examining the movement of the electrometer needle microscopically, an operation which is considered very tiring if carried out for hours at a stretch. A valve method of amplifying the current was therefore adopted. The author has been asked so frequently to give the details of this circuit that it may be

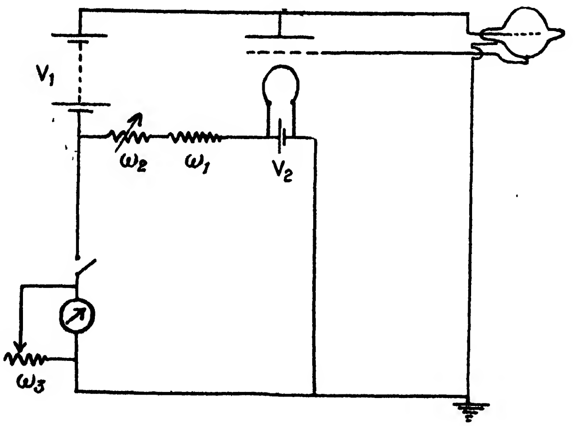


Fig. 4

of use to give them here. The essential principle of the method, which it is believed is now used very considerably, is that the photo-electric cell is connected across the grid and the plate of the valve, as shown in Fig. 4. A galvanometer is placed in the plate circuit, and in order that it shall not receive the full plate current (of the order of several milli-ampères), another current is sent through it in the opposite direction, so that the net current through the galvanometer gives a suitable deflection to the latter. On changing the illumination on the cell, the plate current changes and the galvanometer takes up a new deflection. Actually it has been found quite satisfactory to use the battery supplying the valve filament for neutralizing the plate current through the galvanometer. The circuit is clear from a glance at Fig. 4. V_1 and V_2 are the valve high tension and low tension batteries respectively. ω_1 is the fixed part, ω_2 is the variable part of a resistance in the compensating circuit, and ω_3 is the variable shunt resistance across the galvanometer.

Since the changes in current through the galvanometer are comparatively large, a galvanometer of great sensitivity is not required. It can therefore be designed primarily for a high speed of working, and yet be sufficiently sensitive for the experimental accuracy required. The galvanometer used was specially made up by Messrs Gambrell Bros., and is extremely quick in action and very dead beat, taking about 2 seconds to become steady at its new

* *Proc. Roy. Soc.* **104** A (1923) 248.

deflection when the light intensity on the photo-electric cell is changed. Moreover, it is very robust and does not need any elaborate suspension arrangements.

Details of the circuit used are as follows: Valve D.E. 5 B Osram. $V_1 = 160–170$ volts, $V_2 = 5–6$ volts. $\omega_1 = 1200$ ohms (fixed). $\omega_2 = 400$ ohms maximum (variable). Resistance of galvanometer $= 400$ ohms. $\omega_3 = 400$ ohms maximum (variable), ω_2 and ω_3 are ordinary wireless potentiometers, and provided that special attention is paid to the sliding contacts on them, they work extremely well. The whole of this circuit is now made up, ready for

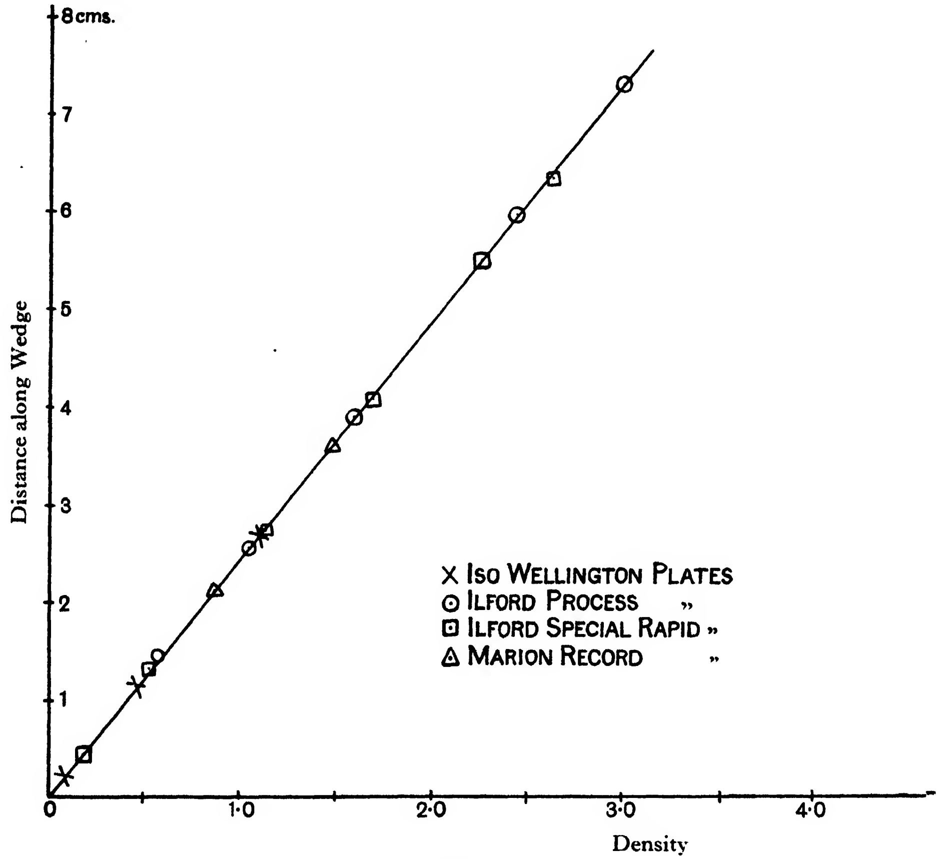


Fig. 5

connecting directly to the density meter, by Kays Instrument Co. of 4 Holborn Place. It is important that the high tension voltage should be supplied by accumulators and not dry batteries.

Since equal distances along the optical wedge correspond to equal increments in density, it is very easy to plot directly on a graph the density values obtained against the logarithm of the corresponding exposures by means of a suitable arrangement of levers attached to the wedge carrier. This automatic plotting device for plotting characteristic curves has already been described by E. R. Davies* and need not be further referred to here, except to say that it is a very valuable addition when, say, from 1000 to 2000 density values have to be measured and plotted in the course of a few days: much time can thus be saved, since the whole operation of writing down figures and plotting them later is obviated.

* *Phot. Journ.* 67 (1927) 178.

Calibration and performance of the instrument.

The machine was calibrated against the Ferguson-Renwick-Benson type of contact opal photometer, the actual instrument being that at the research laboratories of Messrs Ilford, Ltd. A series of negatives of completely different types (as regards size of grain, scattering power, etc.) was measured at Messrs Ilford's and the values obtained plotted against the distances along the optical wedge. A glance at Fig. 5 will show what an excellent straight line relationship exists independently of the type of negative silver measured. From this curve it was found that the distance along the wedge corresponding with a change of unity in density as measured on the F.R.B. photometer was 2·423 cm., and this was therefore the unit taken in calibrating the wedge scale. This method of calibration was the same as that used for the original photometer, so that *for silver negatives*, both machines will give the same result. This allows complete continuity in the work.

Whereas with the original photometer it was with difficulty that a density of 3·0 could be read, with the new one it is possible to make a measurement at about 3·9 using only a 24 watt lamp as the light source and the comparatively insensitive galvanometer already described.

Since equal increments in density correspond with equal decrements in the *logarithm* of the intensity entering the photo-electric cell, and since the photo-electric current is proportional to this intensity itself, it is to be expected that the sensitivity of the recording apparatus will fall off rapidly as the density of the negative under test increases. This is what actually happens, and the maximum sensitivity of the galvanometer is determined by the accuracy of reading required at the highest density measurable, which is nearly 4 in this case. At low densities this maximum sensitivity is very much too great for ordinary work and the galvanometer shunt has to be put in. Some data given in the following table show the relation between given changes in density at various densities, and the corresponding changes in the galvanometer deflection, when there is no shunt across the latter.

Change of density		Change of deflection
From	To	in mm.
0·10	0·12	62
0·50	0·52	50
1·00	1·02	44
1·50	1·52	30
2·00	2·02	12
2·50	2·52	5
3·00	3·05	5
3·80	3·90	2

Since for a given galvanometer sensitivity (as determined by the value of the shunt resistance) the sensitivity of the instrument falls off rapidly with increasing density, it is necessary to arrange that the galvanometer sensitivity shall be increased as increasing

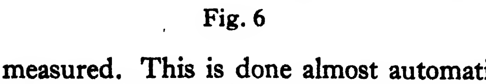


Fig. 6

density values are being measured. This is done almost automatically in the machine in the following way. Let AB (Fig. 6) represent the galvanometer scale, and let C_1 be the position of the spot of light when the density in the machine is zero, the spot moving towards B with increasing density. The position of the *true zero* of the galvanometer (*i.e.* when there is no current through it) is arranged to be at some point off the scale, such as C_0, the spot being brought to C_1 by adjustment of the compensating resistance ω_2 (Fig. 4).

When in this position the galvanometer shunt is largely in, so that the sensitivity is about $\frac{1}{10}$th of the maximum possible. In fact, it is so adjusted that the travel of the spot from C_1 to C_2 corresponds with a convenient increase in density, say from 0 to 1·5.

Now before higher densities can be read the spot of light must be brought back to C_1 again, and since the true zero of the galvanometer is at C_0, increasing the galvanometer sensitivity by altering its shunt resistance will increase the existing deflection C_2C_0, which automatically brings the spot back towards C_1. Thus by suitably choosing the position of C_0, movement of one control knob will ensure that, whatever density is being measured, the spot is on the scale and the galvanometer sensitivity is suitable for the measurement of that particular density. The instrument is thus very nearly automatic.

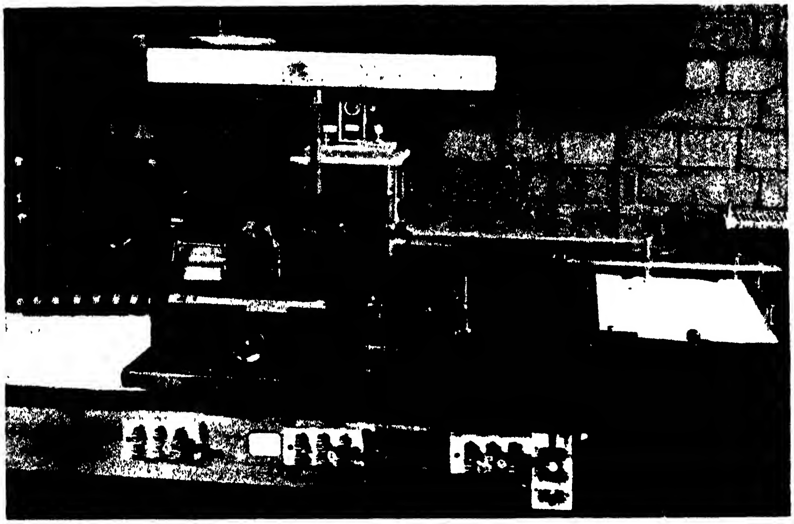


Fig. 7

As originally built the machine was fitted with a small shield over the opal on which the negative is placed in order to prevent light from the room entering the photo-electric cell. This has been found unnecessary in practice, in rooms lit artificially, or even by daylight, provided direct sunlight is not allowed to fall on the negative and the whole aperture of the opal is being used.

In actual use the instrument has been found very satisfactory, and its working speed is at least double that of the old photometer. With very little practice it is possible to measure and plot density values between 0 and 4 at about 5 or 6 per minute.

The density meter is made by Messrs W. Watson and Sons, and the recording apparatus, including the automatic plotter, by Kays Instrument Co. Fig. 7 is a photograph of the complete machine.

In conclusion, the author wishes to express his thanks to Dr T. Slater Price, the Director of Research of the British Photographic Research Association, and to his colleagues, for much valuable advice.

ON A MODIFICATION OF THE CHATTOCK TILTING PRESSURE GAUGE, DESIGNED TO ELIMINATE THE CHANGE OF THE ZERO WITH TEMPERATURE. By

W. J. DUNCAN, B.Sc., A.M.I.Mech.E. of the National Physical Laboratory.

[*MS. received 27th March, 1927.*]

ABSTRACT. A method of avoiding the shift of the zero of the Chattock tilting gauge due to change of temperature is described. The modification of the instrument consists of an additional bulb containing an amount of oil adjusted to secure compensation of the temperature effects.

The creep of the zero which takes place in the ordinary form of the Chattock gauge when the temperature varies is principally due to thermal expansion of the liquids employed. This creep renders constant checking of the zero necessary in work of high precision, and means were sought, whereby it could be more or less completely eliminated. The present paper shows that it is possible to make the gauge self-compensated by providing an additional bulb containing just the right amount of the same oil as that used above the bubble (see Fig. 1).

Let A_R = area of free surface of water in the right hand cup (connected to outer annulus of the central tube).
A_L = area of free surface in left hand cup.
A_0 = area of annular surface of contact of water and oil in central tube.
V_{WR} = volume of water in right hand cup, connecting pipe and annulus.
V_{WL} = volume of water in left hand bulbs and connecting pipes.
V_N = volume of oil ("Nujol") in central tube.
V_{NL} = volume of oil in left hand bulb.
H_R = height of free surface in right hand bulb above surface of contact of water and oil in central tube.
H_N = height of top of bubble above same datum.
H_L = height of free surface in left hand bulb above top of bubble.
ρ_W = density of water (initial).
ρ_N = density of oil (initial).
*α_W = coefficient of expansion of water.
α_N = coefficient of expansion of oil.
*α'_W = coefficient of expansion of water in glass.
α'_N = coefficient of expansion of oil in glass.
t = rise of temperature.

Suppose that everything is initially at a uniform temperature, and let the temperature of the whole gauge rise by the amount t. If the bubble does not move, then the increase of pressure just above the bubble must equal the increase of pressure just below it, provided that the change of surface tension can be neglected (this point is considered below). The condition for no creep of the zero is obtained by the consideration of this equality.

The increase in the volume of oil in the central tube, allowing for the expansion of the

* The coefficients α_W and α'_W are the means throughout the range of temperature considered, since they are not constant.

glass, is $V_N \alpha'_N t$. Hence, since the bubble does not move, the depression of the annular surface of contact of the water and oil in the central vessel is

$$\delta H_N = \frac{V_N \alpha'_N t}{A_0} \qquad \ldots\ldots(1).$$

At the same time the water on the right expands by the amount $V_{WR} \alpha'_W t$ and the whole increase in volume of the liquids on the right is $V_N \alpha'_N t + V_{WR} \alpha'_W t$, which causes the free surface to rise by the amount

$$\delta H_R = \frac{(V_N \alpha'_N + V_{WR} \alpha'_W) t}{A_R} \qquad \ldots\ldots(2).$$

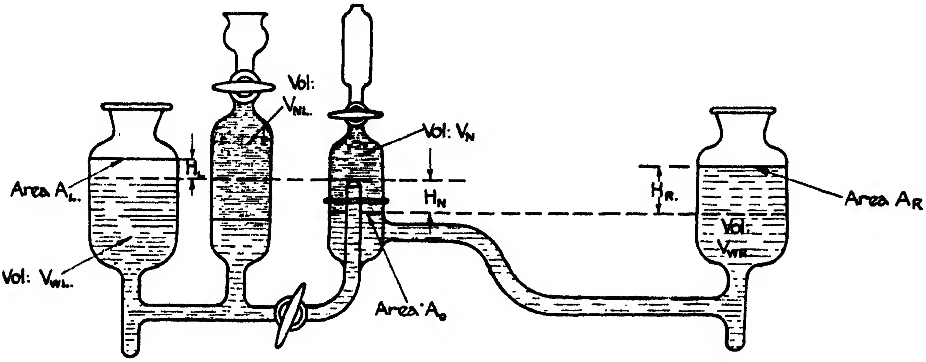


Fig. 1

The increase of pressure above the bubble can now be found. It is

$$\delta p = \rho_W (\delta H_N + \delta H_R) + H_R . \delta \rho_W - \rho_N . \delta H_N - H_N . \delta \rho_N .$$

But $\qquad \delta \rho_W = - \rho_W \alpha_W t,$

and $\qquad \delta \rho_N = - \rho_N \alpha_N t.$

Therefore
$$\delta p = \rho_W t \left\{ \frac{V_N \alpha'_N}{A_0} + \frac{V_N \alpha'_N + V_{WR} \alpha'_W}{A_R} \right\} - \rho_N t . \frac{V_N \alpha'_N}{A_0}$$
$$- H_R . \rho_W \alpha_W t + H_N . \rho_N \alpha_N t \qquad \ldots\ldots(3).$$

The total increase in volume of the liquids on the left is $(V_{WL} \alpha'_W + V_{NL} \alpha'_N) t$, and hence the rise in level of the free surface in the left bulb is

$$\delta H_L = \frac{t}{A_L} (V_{NL} \alpha'_N + V_{WL} \alpha'_W).$$

The increase of pressure below the bubble is

$$\delta p = \rho_W . \delta H_L + H_L . \delta \rho_W$$
$$= \rho_W t . \frac{V_{NL} \alpha'_N + V_{WL} \alpha'_W}{A_L} - H_L \rho_W \alpha_W t \qquad \ldots\ldots(4).$$

The condition for no movement of the bubble is obtained by equating the values of δp in (3) and (4), whence, on dividing by t

$$\rho_W \left\{ \frac{V_N \alpha'_N}{A_0} + \frac{V_N \alpha'_N + V_{WR} \alpha'_W}{A_R} \right\} - \rho_N . \frac{V_N \alpha'_N}{A_0} - H_R \rho_W \alpha_W$$
$$+ H_N \rho_N \alpha_N + H_L \rho_W \alpha_W = \rho_W . \frac{V_{NL} \alpha'_N + V_{WL} \alpha'_W}{A_L} .$$

For initial equilibrium $H_R\rho_W = H_N\rho_N + H_L\rho_W$, and substitution in the last equation gives

$$\rho_W\left\{\frac{V_N\alpha'_N}{A_0} + \frac{V_N\alpha'_N + V_{WR}\alpha'_W}{A_R}\right\} - \rho_N.\frac{V_N\alpha'_N}{A_0} + H_N\rho_N(\alpha_N - \alpha_W)$$
$$= \rho_W.\frac{V_{NL}\alpha'_N + V_{WL}\alpha'_W}{A_L} \qquad \text{......(5).}$$

Put
$$\frac{\rho_N}{\rho_W} = \sigma \qquad \text{......(6),}$$

and note that $\alpha_N - \alpha_W = \alpha'_N - \alpha'_W$, then equation (5) becomes

$$\frac{V_N\alpha'_N + V_{WR}\alpha'_W}{A_R} + \frac{(1-\sigma)}{A_0}V_N\alpha'_N + \sigma H_N(\alpha'_N - \alpha'_W)$$
$$= \frac{V_{NL}.\alpha'_N + V_{WL}\alpha'_W}{A_L} \qquad \text{......(7).}$$

The ratio of α'_W to α'_N depends upon the temperature. Hence, in order that (7) may be satisfied at all temperatures, the coefficients of α'_W and α'_N on the two sides must be separately equated, giving

$$\frac{V_N}{A_R} + \frac{V_N(1-\sigma)}{A_0} + \sigma H_N = \frac{V_{NL}}{A_L} \qquad \text{......(8),}$$

and
$$\frac{V_{WR}}{A_R} - \sigma H_N = \frac{V_{WL}}{A_L} \qquad \text{......(9).}$$

From these equations V_{NL} and V_{WL} can be calculated directly if the other quantities are known.

In the usual form of gauge $A_L = A_R = A$ say. Then equations (8) and (9) become

$$V_N\left\{1 + \frac{A}{A_0}(1-\sigma)\right\} + \sigma A H_N = V_{NL} \qquad \text{......(10),}$$
$$V_{WR} - \sigma A H_N = V_{WL} \qquad \text{......(11).}$$

Numerical example. The following figures refer to an actual gauge:

$V_{WR} = 125$ c.c. $\quad V_N = 17$ c.c. $\quad A_0 = 3{\cdot}53$ cm.^{2}
$H_N = 2$ cm. $\quad A = 18{\cdot}1$ cm.^{2} $\quad \sigma = 0{\cdot}88$ for the oil used.

Hence equation (10) gives

$$V_{NL} = 17\left\{1 + \frac{18{\cdot}1}{3{\cdot}53}\times 0{\cdot}12\right\} + 0{\cdot}88\times 18{\cdot}1 \times 2{\cdot}0 = 59{\cdot}3 \text{ c.c.}$$

and equation (11) gives

$$V_{WL} = 125 - 0{\cdot}88 \times 18{\cdot}1 \times 2{\cdot}0 = 93{\cdot}2 \text{ c.c.}$$

The total volume of liquid on the left $= 59{\cdot}3 + 93{\cdot}2 = 152{\cdot}5$ c.c.

The volume of the left cup and tube which corresponds to a reasonable water level is 75 c.c. Hence the volume of the additional bulb required is $152{\cdot}5 - 75 = 77{\cdot}5$ c.c.

Effect of Surface Tension. The above argument is based on the assumption that changes of surface tension of the bubble are unimportant. This assumption will now be examined.

Let ρ = radius of curvature of the bubble at the vertex (see Fig. 2).
p_0 = pressure just above this point.
p_i = pressure just below the same point.
S = surface tension.

The equation connecting these quantities is

$$p_i - p_0 = \frac{2S}{\rho} \qquad \text{......(12).}$$

As the temperature rises, S decreases, necessitating a decrease of the product $\rho\ (p_i - p_0)$. Since the water is the denser liquid $(p_i - p_0)$ will drop as the bubble rises and at the same time ρ must decrease. Hence both factors become less as the bubble rises and a decrease of the product must be associated with a rise of the bubble. Thus the effect of the variation of surface tension is to cause the bubble to rise when the temperature rises. This effect is in the reverse direction to the displacement of the bubble due to volume changes in the gauge as ordinarily made.

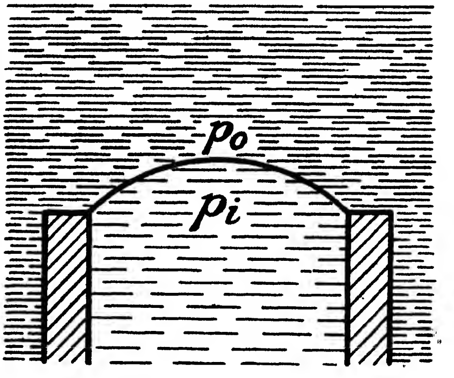


Fig. 2

No actual determinations of the variation of the surface tension between water and "Nujol" appear to have been made. This oil is believed to be a mixture of higher paraffins. The following figures relative to octane are taken from Landolt and Börnstein's tables, and show that the temperature variation is very small. Probably the same is true of "Nujol."

Surface tension between water and octane

Temperature	Surface tension
10° C.	51·01
20° C.	50·81
40° C.	49·58

It thus seems probable that the effect of variation of surface tension with temperature is negligible.

In order to test the efficiency of this method of compensation, an additional bulb was fitted to a standard 26 inch gauge. The modified gauge was placed, together with an unmodified standard gauge, in a cold place for some time; both gauges were then carried into a hot room, and readings of their zeros taken from time to time as the temperature rose. When the gauges had attained the temperature of the room it was found that the zero of the uncompensated gauge had changed by 16 divisions on the wheel, while the compensated gauge only indicated a change of 2 divisions. This small creep could probably be reduced by slightly adjusting the quantity of additional oil used. It is thus demonstrated, both by theory and practical test, that a very considerable improvement in the steadiness of the zero of the Chattock gauge can be attained by very simple means. It is considered that the improvement obtained would in all cases be worth having, and would be especially valuable in work of high precision.

The whole of the preceding argument is based on the assumption that the change of temperature of the gauge is the same in all parts. It is quite evident that the proposed method of compensation will be ineffective against localized temperature changes; indeed it is clearly impossible to make a gauge whose zero shall be unaffected by such changes. In order to minimize the influence of possible inequalities, the additional bulb should be placed as near the central tube as possible.

A DIRECT READING HYDROGEN-ION METER.*

By C. G. POPE and F. W. GOWLETT. Wellcome Physiological Research Laboratories, Langley Court, Beckenham, Kent.

[*MS. received*, 19*th March*, 1927.]

ABSTRACT. An apparatus giving direct readings of hydrogen-ion concentration [*p*H], for use with the hydrogen electrode and quinhydrone electrode, is described. The use of a potentiometric form of circuit and a 4 electrode thermionic valve makes it possible to standardize the apparatus before and after each *p*H reading, by means of a single vernier rheostat. Tables are given showing the accuracy with which it is possible to calibrate the instrument for each range.

Some time ago it occurred to one of us that it might be possible to devise an apparatus for reading *p*H direct from a galvanometer deflection, by using a 3 electrode thermionic valve. In an apparatus of this description the potential to be measured is applied to the grid of the valve in such a way that the grid is always at a negative potential with respect to the negative end of the filament. Under these conditions no current flows in the grid circuit and the apparatus may be considered as a galvanometer of infinitely high resistance. A potential applied to the grid causes a change in the anode current of the valve which can be measured in a suitable manner.

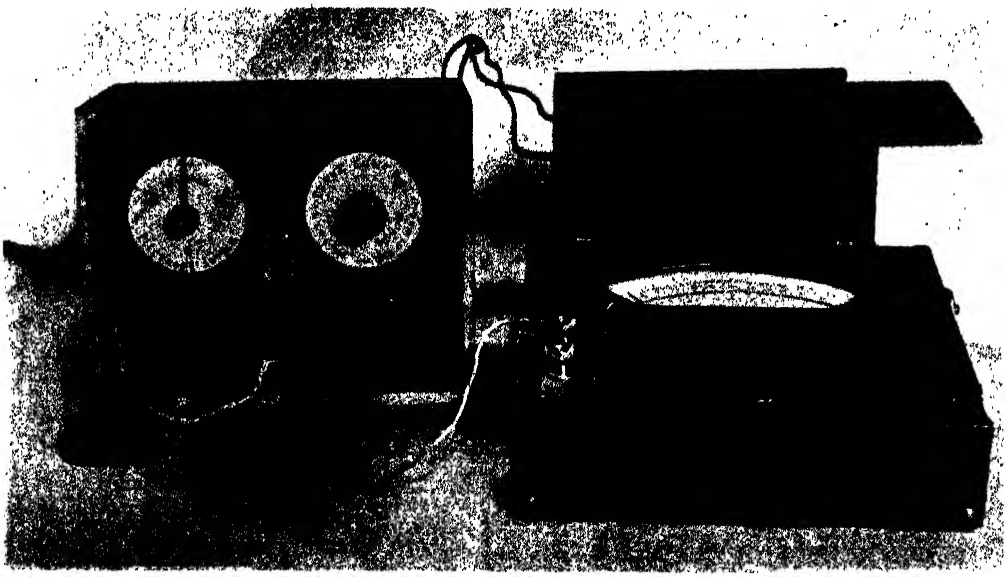


Fig. 1

After the construction of the apparatus had been commenced, our attention was drawn to the fact that a similar apparatus had been described by Goode†. Later‡, he published a description of a modified apparatus in which three 3 electrode valves were used. The change in anode current of the first valve was amplified by the two succeeding valves and the *p*H reading obtained directly on a milliameter.

The chief difficulty we have experienced with apparatus of both types has been due to

* The apparatus was demonstrated at a Meeting of the Biochemical Society in June 1926.

† *Journ. Amer. Chem. Soc.* **44** (1922) 26.

‡ *Ibid.* **47** (1925) 2483.

changes in the potential of the anode batteries. When anode batteries of the type sold for wireless purposes were used, it was found that marked changes in the anode potential occurred, due to the breakdown of a faulty cell. Similar changes were produced by prolonged use of the apparatus. As these changes in the anode potential necessitated a re-calibration of the instrument, the apparatus was unsatisfactory for routine work. Bienfait* has published an improved form of Goode's first apparatus in which arrangements have been made to allow for control of both the anode and filament potentials.

The apparatus to be described in this paper employs one 4 electrode valve, the anode battery as such being discarded, and it is so arranged that the apparatus is standardized before and after each *p*H reading by a single vernier resistance. The chief advantage in

Fig. 2

using a 4 electrode valve lies in the fact that a low anode potential gives an anode current curve similar to that obtained with the 3 electrode valve at a much higher anode potential. This has made it possible to eliminate the anode battery, and by arranging the battery current to pass through a potentiometer, the rheostat (7) could be used simultaneously to adjust the filament current and the anode potential to constant values.

Fig. 1 shows the complete apparatus, set up for reading *p*H by means of the quinhydrone electrode. The terminals on the left are for use with the hydrogen electrode. Fig. 2 shows the internal construction of the apparatus, and Fig. 3 the circuit in diagrammatic form. The numbers given in brackets in the text refer to Fig. 3.

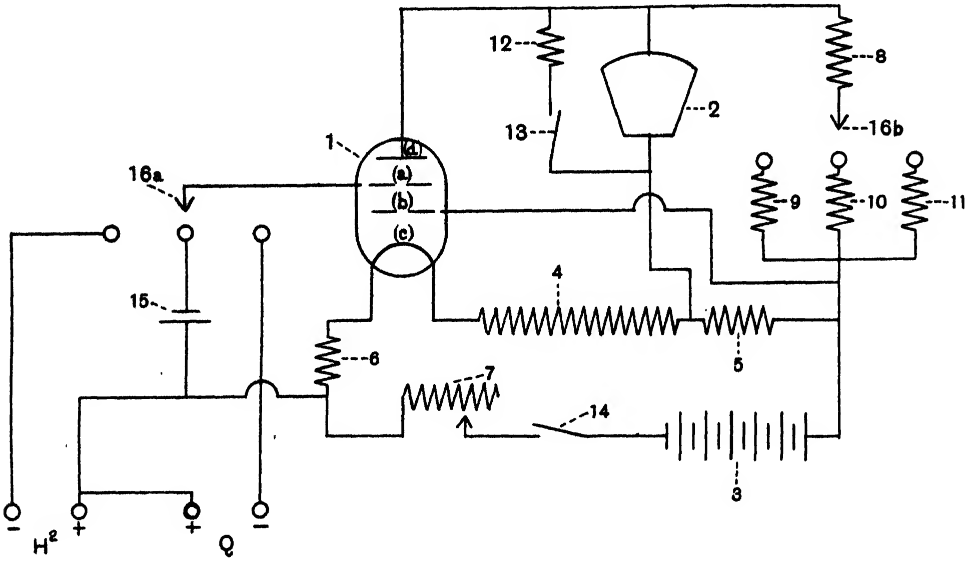
Theory of the Apparatus

The circuit operates in the following manner.

The potential of the electrode system to be measured is applied between the grid of the valve and the end of the bias resistance (6) and alters the anode current from the valve

* *Rec. trav. chim.* 45 (1926) 166.

proportionally to its magnitude. When the grid ((*a*) Fig. 3) is made more negative with respect to the filament the anode current is decreased. Now the normal anode current of the valve is of the order of twelve hundred micro-amperes, and as the milli-voltmeter gives a full scale deflection for a current of 240 micro-amperes, some method must be adopted to balance this normal anode current by passing a current of the same magnitude through the meter in the reverse direction.



(1) Four electrode thermionic valve.
(2) Milli-voltmeter.
(3) 12 volt accumulator.
(4) Main filament circuit resistance.
(5) Reverse current resistance (filament circuit).
(6) Grid bias resistance.
(7) Vernier rheostat.
(8) Main reverse current resistance.
(9) Calibrated reverse current resistance used with the hydrogen electrode system.
(10) Calibrated reverse current resistance used when standardizing the apparatus.
(11) Calibrated reverse current resistance used with the quinhydrone electrode system.
(12) Shunt resistance for milli-voltmeter.
(13) Spring switch keeping the shunt across the milli-voltmeter until the button is depressed.
(14) Main filament circuit switch.
(15) Standard Weston cell.
(16) Double pole three way switch.

Fig. 3. Circuit Diagram

The reverse current is obtained in the following way.

The resistances (4), (5), (6) and the filament resistance (*c*) form a potentiometer circuit, the amount of current passing being controlled by the rheostat (7). If the current is kept constant, the potential differences between the ends of resistances (4), (5), (6) and the filament resistance (*c*) will be constant. It will be seen that two currents can pass through the meter (2) in reverse directions, first, from the valve filament to the valve anode (the electron stream) through the meter to the junction of resistances (4) and (5) and so back through resistance (4) to the filament; second, from the junction of resistance (4) and (5) through the meter, resistance (8) and one of (9), (10) or (11), and thence *via* resistance (5) to the junction of (4) and (5). The amount of current passing through the meter in the

second manner can be controlled by adjusting the resistance values of (9), (10) or (11), and will be dealt with when considering the calibration of the apparatus.

The inner grid of the valve (*b*) is maintained at a positive potential with regard to the filament, by connecting it direct to the positive terminal of the battery (3) as shown in Fig. 3. Its function is that of reducing the "negative space charge," and so lowering the internal resistance of the valve, making it possible to obtain a typical anode current curve with an anode potential of only 10 to 15 volts instead of the higher voltages required for 3 electrode valves. For further details regarding its function reference should be made to a text-book on thermionic valves.

The internal resistance of the valve from filament to anode varies as the potential difference between the filament and anode is varied, and it is therefore necessary to keep this potential difference constant. This is provided for in the present apparatus since, when a constant current is passed through the potentiometric portion of the circuit, the potential difference between the filament and the junction of resistances (4) and (5), to which the anode (*d*) is connected, remains constant.

With a constant filament current and a constant anode potential, the resistance of the valve may now be varied by altering the potential applied to the outer grid (*a*) and so definite changes in the potential of this grid produce definite changes in the value of the anode current flowing through the meter. Assuming that the anode and reverse currents through the meter have been balanced with a definite potential on the grid (*a*) of the valve, any variation in this potential will alter the amount of the anode current passing through the meter and so produce a deflection.

In order that the rheostat (7) may be adjusted until the correct amount of current is flowing through the potentiometer portion of the circuit, it is necessary to apply a constant and easily reproducible voltage to the grid (*a*) of the valve, and then to adjust rheostat (7) until a certain reading on the milli-voltmeter is obtained. The voltage for this purpose is obtained from the Weston cell as shown in Fig. 3. The standardization of the apparatus by means of a known voltage will be dealt with in greater detail under "calibration."

Components

Valve. The valve used in this apparatus is a 4 electrode Osram valve, type D.E. 7. It requires a filament voltage of 1·8 to 2·0 volts, and consumes a current of 0·4 ampere. The valve should show no grid current (outer grid) when the potential applied to the outer grid is zero volts, and the anode current should diminish by at least 300 micro-amperes when the potential on the outer grid is reduced from zero to − 0·7 volt.

Battery. The battery consists of 6 Exide D.T.G. two volt cells connected in series. These cells are capable of supplying the current of 0·4 ampere although they are of small size (rated at 20 ampere hours).

Meter. The instrument is a unipivot milli-voltmeter by the Cambridge Instrument Company, Ltd., used on the 0·0024 volt range; the resistance is 10 ohms and the current required for full scale deflection 240 micro-amperes. As the scale is divided into 120 divisions the instrument gives a convenient reading of *p*H from 0 to 12.

Resistances. The resistances (4) and (5) may be considered as one resistance, with a tapping which is placed at a point to give about $\frac{1}{7}$th of the total resistance. It was made by winding No. 25 S.W.G., D.S.C., Eureka wire on an insulated steel tube. It has been found that the temperature of this resistance does not exceed about 30° C. when carrying 0·4 ampere. Resistances (9), (10) and (11) are wound with No. 34 S.W.G., S.C.C., Eureka wire, on ebonite bobbins. Resistance (8) is also wound with the same wire. In the case of (9), (10) and (11) the ebonite bobbins are made to plug into holders in order that they may be removed easily for calibration purposes or for altering the range of the instrument for

any special purpose. The value in ohms of these resistances will be considered later when dealing with the calibration of the instrument.

Vernier Rheostat. The controlling rheostat (7) is of the Vernier type, with a total resistance value of about 6 ohms. It is essential that this rheostat shall give very smooth control and be capable of fine adjustment, since it is the only control used in setting the instrument to give standard readings. A suitable rheostat may be obtained from the Presland Electric Supplies Ltd., Hampton on Thames. (The Woodhall Vernier Rheostat.)

Shunt Resistance. The shunt resistance (12) and switch (13) are used as a protective device for the meter. This resistance has a value of about 2 ohms, and the circuit is kept closed until the button, seen immediately below the curve control in Fig. 1, is depressed.

Rotary Switch. The rotary switch (16) is a double pole three way switch which connects the grid of the valve to the standard cell or to the desired electrode terminals (16*a*) and at the same time connects the correct resistances in the meter circuit (16*b*), viz. resistance (10) when the standard cell is in circuit, resistance (9) for the hydrogen electrode system and (11) for the quinhydrone system.

The switch shown in Fig. 2 was originally made for a different circuit and appears therefore, to be more complicated than is necessary. Of the studs shown in the photograph only the extreme end and centre ones on each side form part of the circuit.

Method of Calibration

The filament portion of the circuit, which resembles an ordinary potentiometer circuit, will be dealt with first.

The anode battery may be taken as having a potential of from 11·4 volts to 13·2 volts, according to its condition of charge. Under these circumstances a resistance of a value varying from 28·4 to 33 ohms will pass a current of 0·4 ampere, which is required for the valve. Since the valve filament takes 0·4 ampere at 2·0 volts its resistance is 5 ohms. It will be seen that resistances (4), (5), (6) and (7) should have a value varying between 23·5 and 28 ohms, the variations being obtained by means of the rheostat (7). If the grid bias resistance (6) has a value of 0·75 ohm there will be a difference of potential of about 0·3 volt between its ends, which is sufficient to ensure that the grid is always at a slightly negative potential with respect to the filament.

The value for the combined resistance (4) and (5) is about 22 ohms, of which 19 ohms is included in (4) and 3 ohms in (5). Thus the potential difference between the ends of resistance (5) is about 1·2 volts. The circuit was arranged in this manner in order to keep the combined resistance of (8) and either (9), (10) or (11) high (*i.e.* 1000 ohms approximately) compared with the resistance of the meter. The ratio obtained is approximately 1000 ohms to 10.

The General Principle of Calibration of the Meter

The object of calibrating is to obtain the condition where the change in E.M.F. for a difference of one *p*H unit, when applied to the grid of the valve, causes a change in the anode current so that a deflection of exactly 10 divisions is produced on the meter.

The change in anode current for a given grid potential variation may be greater or less than the required amount. In this case it is necessary to alter the slope of the anode current curve by varying the filament temperature. Increasing the filament temperature by reducing the resistance at (7) makes the anode curve steeper and *vice versa*.

The apparatus is calibrated by applying known potentials by means of a potentiometer. A variable resistance box (reading to say 10,000 ohms) is used in place of resistances (9), (10) and (11), these resistances afterwards being wound to the value shown by the variable

resistance box. When a given range has been calibrated by applying known potentials to the grid, some method of standardizing the apparatus before and after each *p*H reading is necessary. For this purpose a known E.M.F. is applied to the grid, and the filament temperature (which is the only variable) is adjusted by means of the rheostat until a predetermined meter reading is obtained. The known E.M.F. may be obtained from a standard Weston cell as shown in Fig. 3, or more simply by connecting the grid directly to the negative end of the valve filament.

Calibration for the Hydrogen Electrode System

Using the saturated calomel half cell at a temperature of 18° C., the change in potential from *p*H 0–12 is from 0·2503 to 0·9427 volt, and the apparatus is arranged to read 0–120 divisions on the scale of the milli-voltmeter when this range of voltages is applied to grid (*a*). This is done by adjusting the value of the resistance at (9) in the following manner.

Set the rotary switch (16) to the H_2 electrode terminals and connect a potentiometer to these terminals so that its negative lead goes to the grid of the valve. Apply a potential of 0·2503 volt from the potentiometer to the outer grid. In the position which will finally be occupied by resistance (9) connect the variable resistance box; adjust the resistance box until the reverse current is about equal to the anode current from the valve. Great care must be taken to prevent damage to the meter during these balancing operations. The shunt (12) across the meter must not be removed by depressing the button (13) until it is obvious that the anode current is almost balanced by the reverse current. The meter should be so connected that increasing the reverse current increases the meter reading.

Now make adjustments by means of the rheostat (7) (controlling filament temperature and therefore the slope of the anode current curve); at the same time adjusting the resistance at (9) by means of the resistance box until, with a potential of 0·2503 volt on the grid, the meter reads 0, and with a potential of 0·9427 volt it reads 120 divisions. As the anode current curve is not an absolute straight line, it is then advisable to apply to the grid the potential for *p*H 7·0, and by very slight alteration of the rheostat and resistance box adjust until the meter reading is exactly 70 divisions. The lowest and the highest readings may not quite fit the meter scale, but the deviations should be very slight. Table I shows the results

Table I. *Calibration Table showing results obtained with the present apparatus for the Hydrogen Electrode System.*

H_2 electrode—Sat. Calomel Cell. $T = 18°$ C.

E.M.F. applied to grid	Corresponding *p*H	Meter reading divisions		Error in *p*H
0·2503	0	0·9		+ 0·09
0·3080	1	10·0		0·00
0·3657	2	20·0		0·00
0·4234	3	30·0		0·00
0·4811	4	40·0		0·00
0·5388	5	50·0	Standard	0·00
0·5965	6	60·0	reading	0·00
0·6542	7	70·0	60 divisions	0·00
0·7119	8	80·0		0·00
0·7696	9	90·0		0·00
0·8373	10	100·2		+ 0·02
0·8550	11	110·9		+ 0·09
0·9427	12	122·0		+ 0·20
0·2503	0	0·0	Standard	0·00
0·8550	11	110·0	reading	0·00
0·9427	12	120·2	59 divisions	+ 0·02

The standard can be adjusted to 59 as shown to correct the 0, 11 and 12 *p*H readings when these are used.

obtained with the present apparatus, and gives the method used to correct the end readings. A resistance coil having the value in ohms indicated by the variable resistance box can be constructed and substituted for it.

The "standard" resistance coil (10) can now be calibrated. Connect the variable resistance box in the position to be occupied by resistance (10). Apply the constant voltage of the Weston cell to grid (*a*) by turning the switch (16) to the standard position. Adjust the resistance box until the meter reads about 60 divisions with the button (13) depressed, care being taken to protect the meter by means of the shunt until the anode and reverse currents are about balanced. Now apply a definite potential to the H_2 terminals by means of the potentiometer, *e.g.* that for *p*H 7·0, and adjust the rheostat (7) until the meter reads exactly 70 divisions, having of course turned switch (16) to the H_2 position. Rotate switch (16) back to the standard position and adjust the resistance box only until the meter reads 60 divisions (or other convenient reading).

When using the apparatus for measuring *p*H this procedure is reversed; the switch (16) is set at "standard" and the rheostat (7) adjusted until the reading of 60 divisions, or such other value as may have been chosen, is obtained. The instrument then reads correctly, and by applying the E.M.F. for any *p*H from 0 to 12 to the H_2 terminals and rotating switch (16) to the "H_2 position," the correct reading on the meter is obtained. In practice this "standard reading" is taken before and after each *p*H reading, and any adjustment necessary, due to a drop in the potential of the battery (3), is made by means of the rheostat (7).

The resistance (10) may now be wound to the value shown by the variable resistance box, and inserted in its proper position.

Calibration for the Quinhydrone Electrode System

The system used is based on Veibel's* quinhydrone half cell, and is as follows:

$T = 18°$ C.

Au	*p*H 2·0 buffer Sat. Quinhydrone	Sat. KCl Agar bridge	*p*H *X* Sat. Quinhydrone	Au

In this case, when the *p*H of *X* is 2·0 the E.M.F. will be zero, while at *p*H 0 it will be + 0·1154 volt, and at *p*H 9, − 0·4039 volt.

The apparatus used for the quinhydrone electrode may be seen in Fig. 1. It consists of an ebonite base, drilled with two holes. These contain mercury which makes contact to the two terminals. Two lengths of glass tube, 70 mm. long by 6 mm. internal diameter, have short lengths of platinum wire fused into their ends, the wire inside the tubes being heavily gold plated. Connexion between the two tubes is made by means of a U-tube capillary filled with agar saturated with KCl. One tube contains the standard buffer solution saturated with quinhydrone and the other the solution whose *p*H is being determined, also saturated with quinhydrone.

Place the variable resistance box in the position to be occupied by resistance (11) and rotate the switch (16) to the quinhydrone position. Adjust the resistance box and rheostat (7) until the meter reads 20 divisions with zero E.M.F. applied to the quinhydrone electrode terminals, and 120 divisions when the E.M.F. is 0·5570 volt. (The negative lead of the potentiometer goes to the grid of the valve.) Now apply the E.M.F. for *p*H 7·0 and make small adjustments with the rheostat (7) and the variable resistance box until the meter reads exactly 70 divisions. With the meter reading exactly 70 divisions, rotate switch (16) to the standard position and note the reading obtained. (The standard reading will of course be different from that for the hydrogen electrode system.) This is the standard reading

* *Journ. Chem. Soc.* (Sept. 1923) 2203.

for this particular quinhydrone electrode system, and should be obtained by adjustment with rheostat (7) before each reading with the quinhydrone electrode and also checked after each reading.

The resistance (11) should be wound to the value shown by the variable resistance box.

In using the quinhydrone apparatus described, the terminal from the tube containing the liquid whose *p*H is being determined is connected to the grid, *i.e.* to the terminal marked *Q*− in Fig. 3.

The calibration values for this electrode system, obtained with the present apparatus, are shown in Table II. The small error in the readings at *p*H 0 to 3 can be corrected by lowering the standard reading as shown.

Table II. *Calibration Table showing the results obtained with the present apparatus for the Quinhydrone Electrode System.*

E.M.F. applied to grid	Corresponding *p*H	Meter reading divisions		Error in *p*H
+ 0·1154	0	1·0		+ 0·10*
+ 0·0577	1	10·5		+ 0·05*
0·0000	2	20·3		+ 0·03*
− 0·0557	3	30·0	Standard	0·00
− 0·1154	4	40·0	reading	0·00
− 0·1731	5	50·0	72 divisions	0·00
− 0·2308	6	60·0		0·00
− 0·2885	7	70·0		0·00
− 0·3462	8	80·0		0·00
− 0·4039	9	90·1		+ 0·01

* By adjusting the standard reading to 71 instead of 72 divisions *p*H 0 to 3 gave correct readings. The calibration was not continued above *p*H 9, as this represents the upper limit at which the quinhydrone electrode is of service for the determination of *p*H.

When using the apparatus it is only necessary to adjust the rheostat (7) to make good any drop in the potential of the battery (3), and of course when changing from the hydrogen electrode system to the quinhydrone electrode system, where the "standard reading" values may be, as in the case of the present apparatus, 60 and 72 divisions respectively.

The values given in this paper for the various resistances are only approximate, since they were those required for a particular valve, and will differ, although possibly only slightly, for other valves. The actual calibration is however, quite simple, and although only two systems are described it is obvious that many variations may be introduced for the measurement of various ranges of E.M.F.

The apparatus described has been in almost daily use for a period of nearly 12 months. During this time no significant alteration affecting the accuracy of the readings has taken place. Certain precautions should, however, be taken in use. All contacts should be kept perfectly clean, otherwise unwanted resistance may be introduced into the circuit which would affect the readings. The apparatus should be kept in a room of fairly even temperature, as large temperature variations will upset the values of the resistances. When replacing a discharged battery by a fully charged one, great care should be taken to see that the rheostat (7) is so adjusted that almost the whole of its resistance is in circuit. Unless this is done, too heavy a current will be passed through the valve filament, with a risk of altering the characteristic curve of the valve.

EXPERIMENTAL RESEARCH ON ELECTROSTATIC VOLTMETERS. By E. H. W. BANNER, M.Sc., A.M.I.E.E., A.Inst.P.

ABSTRACT. The paper describes briefly various experimental work performed with the object of reducing the range of an electrostatic voltmeter. It was hoped to use water as the dielectric ($\epsilon = 80$) in order to increase the torque and so lower the full-scale voltage. The conductivity of distilled water was found to be far too high, however. Methyl alcohol ($\epsilon = 34$) was also tried and abandoned for the same reason.

Experiments were made on a cylindrical vane-type of electrostatic voltmeter in paraffin. Under certain conditions the increase in scale for a given voltage was approximately proportional to the dielectric constant of the paraffin. Unless care is taken the mechanical properties of the liquid swamp the electrical force entirely.

Another design of instrument with a constrained-strip suspension was tried and found to have its calibration directly proportional to ϵ, the mechanical effects being eliminated. The reduction of voltage for full-scale was only $1/\sqrt{2}$ however, and hardly appreciable.

Dr Drysdale in his lecture at the Exhibition of the Physical Society on 5th January, 1927, Part 2 of which is published in the *Journal of Scientific Instruments*, vol. IV, no. 7, quotes the possibility of increasing the torque of an electrostatic voltmeter in various ways as a means of producing a low-range instrument.

A number of experiments of a similar nature were made by the author some years ago in the electrical laboratories of the University of Birmingham, and it now appears opportune to publish some of the results.

It can be stated at the outset that the results were negative, and that a portable low-range electrostatic voltmeter was not produced, although there are certain lines of experiment which still appear to be worth trying, but lack of facilities and time prevents their prosecution at present.

The use of a medium of high dielectric constant was the first idea, and as water is rated as having a dielectric constant of about 80 this was first tried. Gases are of no use, as their dielectric constants are all nearly unity. For testing the conductivity of distilled water a cell was constructed having two electrodes immersed in the test liquid. A brass sphere of 1 cm. diameter was fixed opposite a disc of 4 cm. diameter. The gap was provisionally fixed at ·5 cm. With an applied P.D. of 1 volt D.C. a current of 16·6μA passed at 14·5° C. Decreasing the gap to ·2 cm. increased the current to 24·5μA. Water from another source was then obtained, and was stated to be the purest obtainable. This had a conductivity of 41·0μA at 1 volt. This order of conductivity is far too great, as electrolysis would very quickly upset any calibration*. Methyl alcohol, $\epsilon = 34$, was tried next; this showed a conductivity of 10μA at ·2 cm. with 1 volt, and was also abandoned for the same reason.

For high insulation an oil was decided on, but the dielectric constant being about 2 for paraffin, the increase of voltage range was only expected to be 2, or full-scale obtainable for $1/\sqrt{2}$ times the voltage of an air instrument. For the initial experiments an Ayrton-Mather voltmeter was used. This was of the cylindrical vane type, range 130 volts. The instrument was immersed bodily in the oil contained in a glass vessel, and three distinct phenomena occurred, depending on the oil level relative to the instrument.

1. Fully submerged.
2. Vanes submerged, spring clear of paraffin.
3. Top of vanes above oil level.

* It appears to the author that the convection currents and bubbles noticed by other workers may be due to actual conduction through the liquid.

In the first case Fig. 1 shows graphically the result.

At a certain critical voltage movement commenced and continued to full scale, reducing voltage caused a reversal of this, but at a different critical voltage.

Case 2. Here the readings were 1·64 times true volts, and apart from some sluggishness seemed to be satisfactory, and proved the contention.

Case 3. In this experiment no readings were obtainable.

A film of paraffin was drawn up the vanes and inductors by surface tension and in order to enclose the least area it pulled the vane into the inductors, i.e. full-scale position. This was quite independent of any voltage applied to the terminals.

These three tests showed that although it was possible to obtain an increase of scale reading approximately proportional to the dielectric constant of the liquid used, the movement needed a radical departure in design in order to prevent the mechanical properties of the fluid from swamping the working torque altogether.

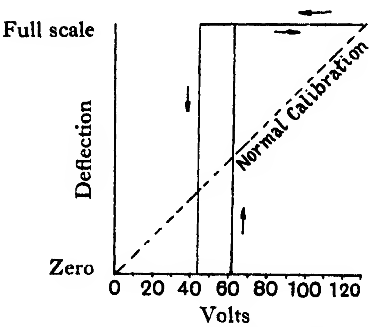


Fig. 1. Ayrton-Mather Voltmeter in Paraffin

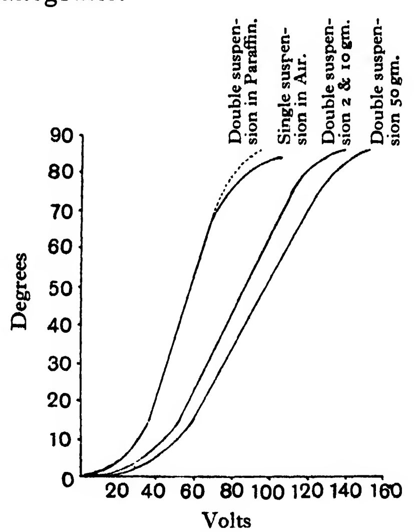


Fig. 2. Experimental Instrument in Air and Paraffin

Apart from the use of dielectrics other than air it was considered that a reduced torque in an instrument was permissible if pivot friction were entirely absent. To explore this and to have a model for further paraffin-dielectric tests, an instrument was designed and made having two pairs of 45° inductors with a horizontal vane of the shape of that used by Rayner*. The vane was constrained to its position by a strip suspension above and below, similar to the marine galvanometer of Sullivan. In this way pivot friction was eliminated and a fairly robust and semi-portable instrument obtainable. The calculated torque was ·03 cm. gm. No damping was included, as for the purpose of these tests it was not required and with oil immersion would have complicated the matter. To the lower strip a weight was attached. This was guided so that it did not rotate, as the lower end of the strip was constrained to move vertically only.

Calibrations were made with various weights and, contrary to expectations, the deflection for a given voltage was not quite independent of added weight, although this weight was not productive of an increased movement of inertia of the vane. The reduction of deflection for a given voltage was of the order of 3 per cent. when the weight was increased from 10 or 20 gm. to 50 gm. Fig. 2 shows the calibration of this experimental instrument in air and in paraffin, and, in air, with different tensions of the suspension.

* Rayner, *J.I.E.E.* 59, 138.

The immersion in paraffin shows a factor of 2, so that the curves for single suspension in air and double suspension in paraffin are coincident where the curve is linear.

A comparison of these results with the previous ones shows that (1) the control must not be affected by the liquid dielectric used, and (2) the vanes and inductors must be entirely submerged; then the increased deflection is approximately proportional to the dielectric constant of the liquid. Variation of dielectric constant with temperature was not experimented with, but it appears to the author that the mechanical effects, such as variation of viscosity and surface tension, would be negligible in view of the two conditions imposed above.

The use of an oil of $\epsilon = 5$, as suggested by Dr Drysdale, should be of value, as the factor of 2 for paraffin is hardly noticeable as a reduction of scale. The author could not find a liquid with this property other than castor oil, which appeared to be too viscous at the time of making the experiments detailed.

Finally, the results of the experimental work performed showed that, at least on the lines attempted, a low-range (say 20 volt) electrostatic voltmeter, to be portable and fairly robust, was not practicable. It might be possible to effect an appreciable reduction by the use of methods other than those described, or by the use of the oil described by Dr Drysdale in his lecture, or any other highly-insulating fluid of high dielectric constant.

NEW INSTRUMENTS

THE THOMAS ELECTRICALLY RECORDING GAS METER

THE CAMBRIDGE INSTRUMENT COMPANY have just issued a list No. 151 containing an interesting description of the above instrument, which is suitable for measuring and integrating the

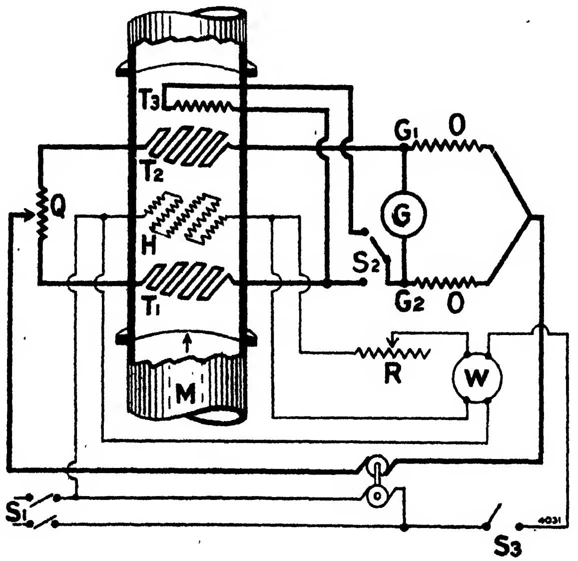


Fig. 1

rate of flow of large quantities of gas, from 25,000 to 750,000 cubic feet or more per hour. It was devised by Professor C. C. Thomas of the University of Wisconsin, who found that the specific heat per cubic foot of industrial gas is independent over a wide range of variations in its temperature, pressure, density, or composition. In consequence, the amount of energy

required to raise the temperature by a given amount, say two degrees Fahrenheit, is simply proportional to its rate of flow, which can therefore be indicated by a wattmeter or integrated by an electrical energy meter. Fig. 1 shows the schematic arrangements of this meter, where H is the heating grid supplied with power from the electrical supply mains, which is indicated on the wattmeter W, and T_1 and T_2 are nickel wire resistance grids, connected as a bridge with the ratio coils OO, the out-of-balance current being indicated on the galvanometer G. As the grids T_1 and T_2 are of exactly equal resistance, and would therefore

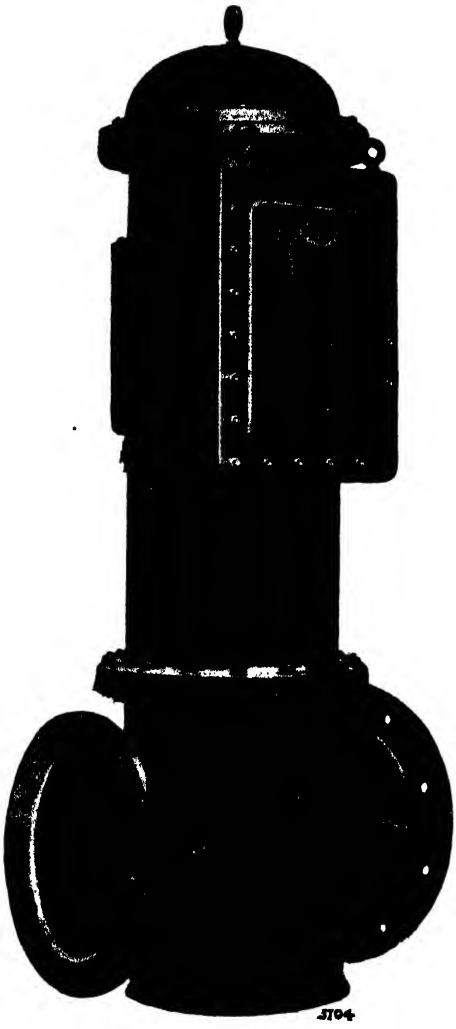


Fig. 2

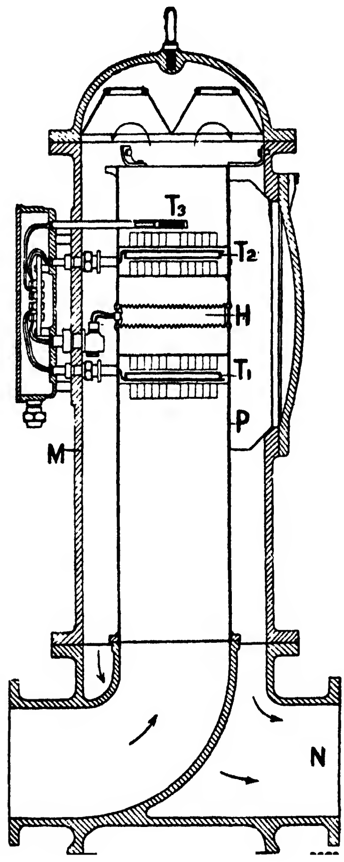


Fig. 3

balance when there is no difference of temperature between them, a third grid T_3, having the small resistance necessary to produce balance when T_2 is 2° F. higher in temperature than T_1, is fixed above the former, and gives automatic correction in that position for variation in the water content of the gas, the readings being given in terms of standard cubic feet of saturated gas.

Two types of this meter are made. One of these, the Return Flow Type (Figs. 2 and 3), is used for rates up to 50,000 cubic feet per hour, and the other, the Vertical Type, for higher rates, where the sudden reversal of flow would cause an undesirably large drop of gas pressure. The arrangements shown in Figs. 2 and 3 will be self explanatory from Fig. 1,

but a further point to notice is the jacketing of the measuring portion of the tube by the return flow, which prevents any local external temperature variation from affecting the readings. The drop of pressure in this type is about 1 inch of water at full duty, but is

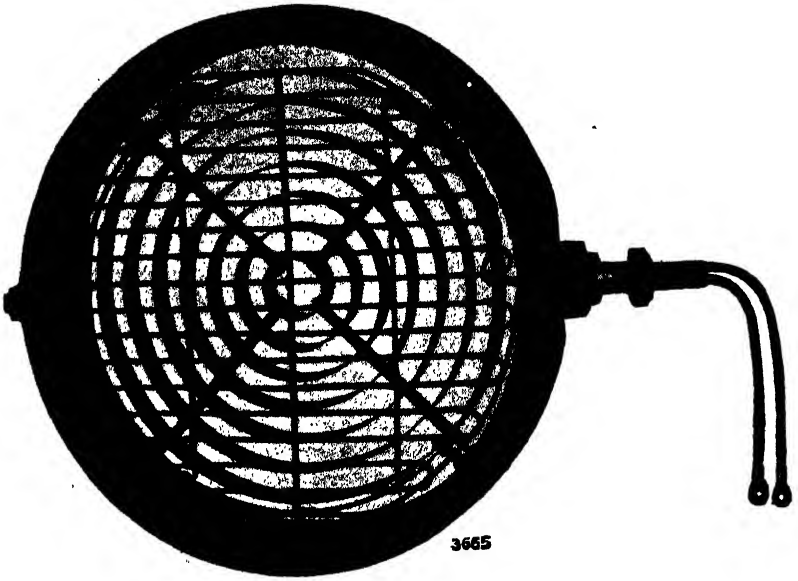


Fig. 4. Thermometer unit

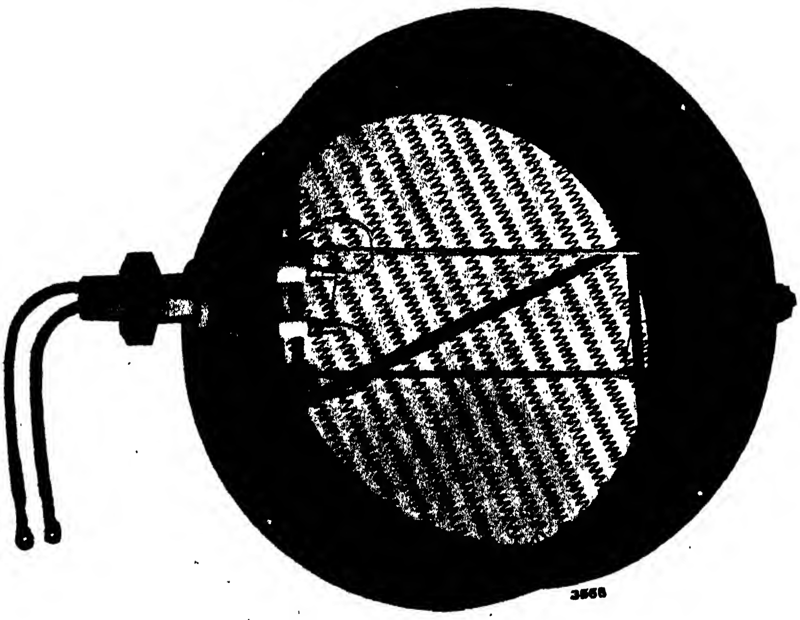


Fig. 5. Heater unit

only about one-third inch at half load. As this type of meter would become unduly large for greater flows, if the back pressure is not to be increased, a single tube only is used in the vertical type and the back pressure is reduced to half an inch or less. As regards the thermometer and heater grids, both of which are made up as ring units (Figs. 4 and 5), the former are wound in zigzag form with 42 S.W.G. nickel wire, triple silk covered, sleeved

and lead sheathed to prevent corrosion. Concentric hoops of sheet iron are provided to shield the wire from oblique or reflected radiation from the heater. The latter is wound, in similar fashion, with spiralled nickel chrome wire of No. 14 to 19 S.W.G., according to the size of the housing and voltage of supply, across a seamless paxolin tube provided with flanges to which the thermometer rings are screwed, so as to be exactly equidistant from the heater grid.

The essential features of the operating and measuring apparatus are the automatic regulator, which varies the current in the heater so as to maintain the constant difference of 2° F. between the thermometer grids; a recording wattmeter; and an energy meter for indicating the total volume. These may be in any convenient position, and the only item which requires description is the regulator, which is diagrammatically shown in Fig. 6.

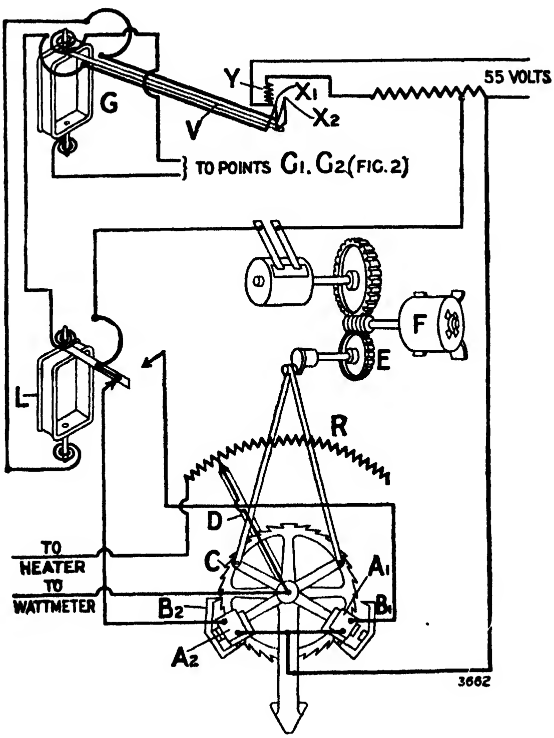


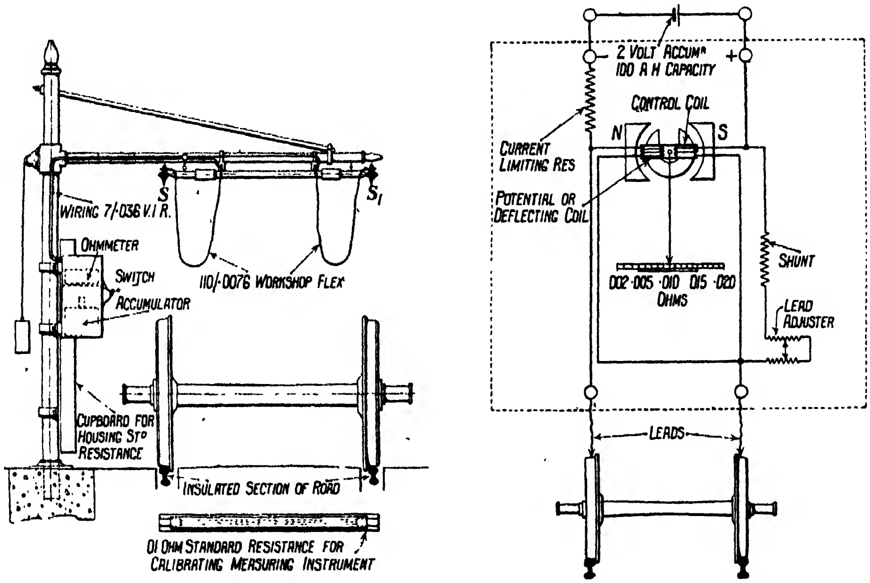
Fig. 6

The moving coil galvanometer G carries two opposed thermo junctions X_1 and X_2 on its pointer which move close to a small electrically heated coil Y, and these thermo junctions are connected to the coil of a robust moving coil relay L. A small continuously running motor F is provided with an eccentric which keeps two pawls B_1 and B_2 in oscillation close to a ratchet wheel C, with reversed teeth on its two halves, and these pawls are brought into action by the electro-magnets A_1 and A_2, which are energised through the local contacts of the relay L. If the temperature difference is less than 2° F. magnet A_1 is energised, which causes the ratchet wheel with the contact arm D to rotate in a counter clockwise direction and cut out part of the resistance R in series with the heater. Either direct or alternating supply at 110 or 220 volts can be employed if the magnets and rheostats are wound to suit.

The pamphlet contains an interesting description of the method of adjustment and testing of the meters. The final test is made by drawing air through the meter, which is connected to a wind channel in which the flow is measured by calibrated orifices, and a Krell gauge previously standardised by a Threlfall micro-manometer.

RAILWAY WHEEL BONDING TESTER

Messrs Evershed & Vignoles, Ltd., have recently introduced a portable instrument for testing the resistance of the bonding of railway wheels. As on many English railways wheels of the Mansell type are used, in which the tyre is supported by wood to give greater resilience, thus partially insulating the tyre from the axle, track circuit devices can only be operated by bonding the tyres to the axles, and it is important that the resistance of these bonds should be low in order to eliminate the risk of false "line clear" indications. Until recently a resistance of 0·1 ohm from tyre to tyre of a pair of wheels was considered sufficiently low, but the Railway Standards Committee have now adopted 0·01 ohm as the limiting maximum resistance, requiring a new type of instrument to measure the resistance rapidly and with sufficient accuracy.



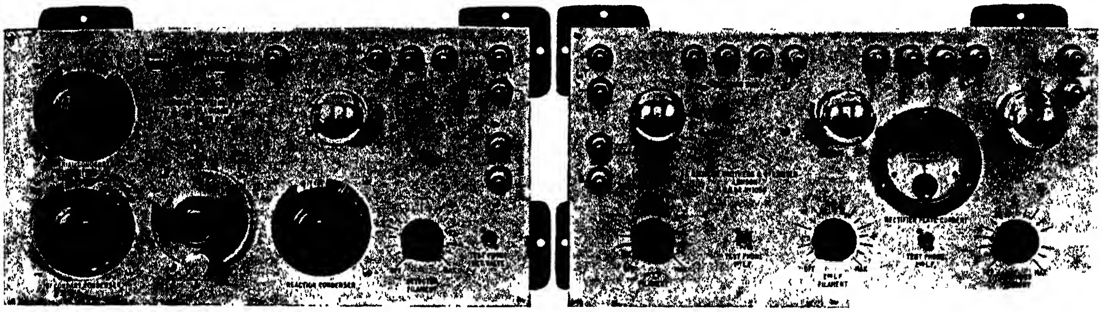
Arrangement and Electrical Connections of Wheel Bond Testing Equipment

In co-operation with the staff of the London and North Eastern Railway the firm has evolved a portable testing instrument which is in general use on that railway. As would be expected, the instrument is on the well-known ohmmeter principle, containing a moving coil instrument with two coils on a common frame, which envelop the two halves of an iron core in the field of a permanent magnet. One of these coils is in series with, and the other is shunted across, the testing leads, and the pointer indicates the resistance between them directly, on a scale reading from ·002 to ·02 ohm, the portion between ·005 and ·015 ohm being coloured green to indicate the ordinary limits.

Current is supplied from a two volt cell through a limiting resistance, and an adjustable shunt is provided to the current coil for correcting any change in the resistance of the leads; a standard bar of ·01 ohm resistance being provided for checking. The resistance of the contacts is included in the reading, as there are no separate potential terminals, so that it is imperative that the contact spikes should be kept clean, and be held in firm contact against the tyre surfaces. Fig. 1 shows the diagram of connections, and the arrangement of the outfit for testing on the track, which will be readily understood.

AUTOMATIC WIRELESS ALARM DEVICE

Messrs Siemens Brothers and Co., Ltd., have just issued a leaflet No. 2051 describing a new automatic alarm device for giving warning on a vessel in which a constant watch cannot be kept. It has been designed to comply with the Draft British Technical Wireless Regulations of the Committee of Imperial Defence, and is arranged to give an alarm when a signal is received consisting of 12 four-second dashes separated by intervals of one second. Two panels are provided, the first being a tuner panel, with single-valve detector, responding



Siemens Auto Alarm Device

to wave-lengths between 585 and 615 metres, with a note frequency of not less than 100 $\sim$ per second. The second panel comprises a two-valve amplifier and single-valve rectifier, which operate a relay in a selector circuit. This selector has a contact mechanism which causes an alarm bell to ring after the series of dashes composing the alarm signal has been received, but declutches and returns to rest if it has been started by any other signal, and the standard sequence of dashes is not maintained. Each panel is mounted on a cast iron water tight box containing the apparatus. The valves are mounted on the panels, and if any valve should break down arrangements are provided to cause the bell to ring.

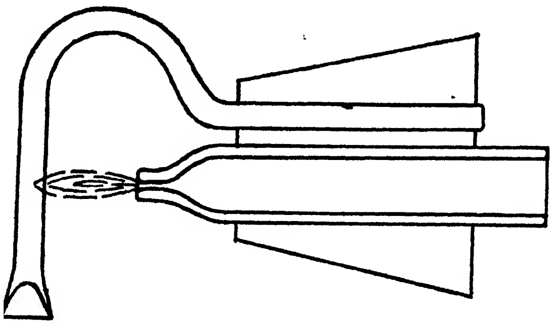
LABORATORY AND WORKSHOP NOTES

A SIMPLE SOLDERING DEVICE. By WILLIAM CLARKSON, M.Sc., A.Inst.P.

A simple self-heating bolt, suitable for the soldering of small parts and readily adaptable to varied situations where the parts are difficult of access, may be constructed from a piece of stout copper wire and a pin-hole glass gas-jet. The jet is fixed in a cork, and the wire is shaped and mounted, as shown in the figure, so that the tip of the jet just impinges upon it. The mounting should be rigid. The gas is supplied by ordinary rubber, or other, flexible tubing (not shown), which forms, with the cork and jet, a convenient non-conducting handle.

Three-millimeter diameter wire is very suitable, but wire of any dimensions or disposition, with tips of various forms, may be employed. Once a mount and jet are available, a new bolt, suited to any special circumstances, may be made and fitted in five minutes, or a supply may be kept at hand. It is not necessary, of course, that a cork or similar mount be used; the wire may be flattened and bound to the jet itself.

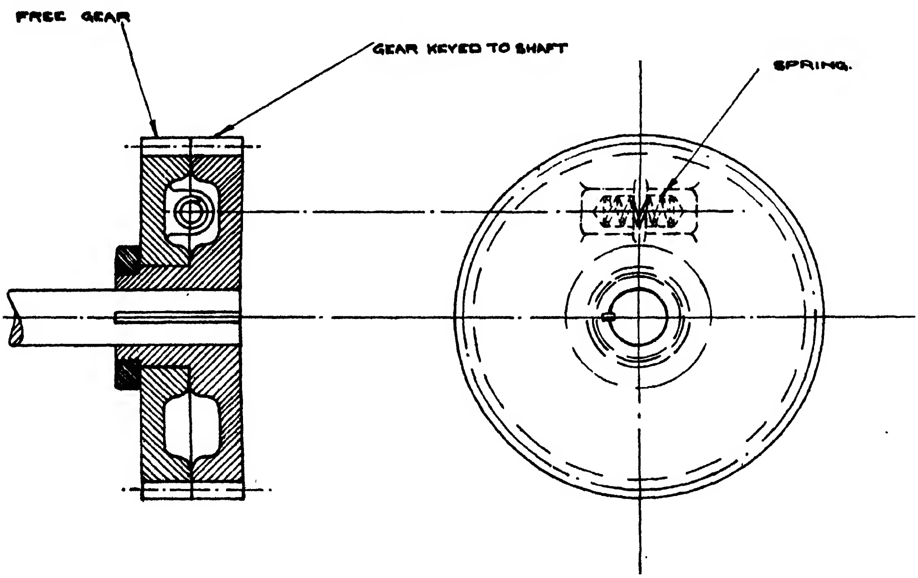
With regard to the jet, it may be made of fairly stout glass tubing, say one centimeter in diameter, drawn to a fine tip. If the walls of the jet are well thickened before drawing, this also serving to diminish the bore, such a jet is sufficiently robust for all practical



purposes. Alternatively it may be made by drilling a fine hole in a plugged metal tube. In this case several holes, or even a hammered slit, may be used if required. It is necessary to see that the gas flame is not so large as to be inconvenient in working, and not so disposed that the soldering tip, the flux or the parts to be soldered may be attacked.

PREVENTION OF BACKLASH IN GEARING

A COMMON way of masking backlash in a train of mechanism is to apply friction to the operating or driving member by means of a spring washer or some such device, so that



Removing Backlash from Gearing

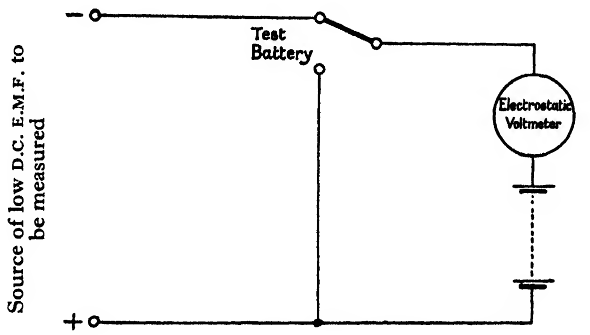
it is not free to rattle and the backlash is not felt. This expedient, however, is useless in apparatus where more than merely a satisfactory "feel" is necessary, and in such cases it is usual to employ springs to ensure that the loading on the important members is never reversed. The accompanying illustration shows an application of this method to gearing.

Here one of the two meshing gears is divided in its own plane. One only of the two sections is fixed to the shaft. The other is urged rotationally by a spring, which causes the two to engage both flanks of the teeth of the meshing gear. It is obviously essential (1) that when the tongue is in the direction of normal running under load, the load should be carried by the fixed gear, and (2) that the spring should have sufficient initial load not to yield when the direction of rotation is reversed.

THE TAYLOR-HOBSON RESEARCH LABORATORY,
LEICESTER.

READING LOW D.C. VOLTAGES ON AN ELECTROSTATIC VOLTMETER. By E. H. W. BANNER, M.Sc., A.M.I.E.E., A.Inst.P.

ELECTROSTATIC voltmeters, apart from electrometers and delicate suspended non-portable instruments, are not practicable for a lower full-scale voltage than about 80–120. Whatever the length of scale, it is unusual to be able to make use of the initial 20–25 per cent., as the scale divisions are so crowded. Magnification of the scale is of no intrinsic value, as the accuracy is inherently low at small deflections.



It is, then, not usual to be able to read less than about 20 volts, although at about three-quarters of full scale a change of about ·5 volt may be read with considerable accuracy. In order to read low voltages of less than 20 volts a voltmeter and battery are required. A dry battery of small current capacity may be used, as it only has to supply the charging current of the voltmeter on switching on, which is practically negligible. The voltage of the battery must be such as to enter on the open part of the voltmeter scale, say 20–30 volts. The battery is connected in series with the voltmeter across the points required, the two polarities being additive.

An applied D.C. potential difference of, say, 2 volts, will be read as $E_{\text{batt.}} + 2$ volts, so that the battery voltage must be known and subtracted. The circuit shown in the diagram is useful to read the battery voltage, and as this may be done immediately before and after a test, any change in the battery during the test may be allowed for.

A modification of this artifice may be used to read a D.C. voltage greater than that read by the voltmeter. The dry battery is then reversed, the true voltage being the voltmeter reading plus the battery voltage. The same circuit suffices, with the polarity of the battery shown reversed.

The use of an electrostatic voltmeter for low D.C. voltages is generally restricted to measurements where no current may be taken from the circuit.

CORRESPONDENCE

COST OF ENGLISH INSTRUMENTS

I WAS interested in seeing the letters from Sir W. N. Shaw and Mr Taylor on the above subject in your *Journal* of July with reference to the Aitken Dust Counter.

Not having seen the first letter from Sir W. N. Shaw it may be that I am ignorant of some important facts, but surely it appears that here is a case of "much ado about nothing." The reason why the Aitken Dust Counter is no longer available is surely that it has been superseded by the Owen's Dust Counter, made by Casella and Co., and though there may be certain differences in construction, generally the principle remains the same.

I venture to think that if Sir W. N. Shaw approached the bicycle manufacturers for a tall machine as used in 1880, he might experience the same difficulty in obtaining the desired article.

P. E. NEGRETTI.

38 HOLBORN VIADUCT, E.C. 1.

REVIEWS

The National Physical Laboratory. Report for 1926. H.M. Stationery Office. Pp. 260. Price 7*s*. 6*d*.

This voluminous Report covers the activities of the Laboratory for the past year in the fields of general research, maintenance of standards, Government research, special investigations, and test work. On account of the importance of the work and the conciseness of the Report, a rather lengthy review is desirable, extending over several issues of this *Journal*. In the present issue the work of the Physics Department is described.

PHYSICS DEPARTMENT

I. Heat and General Physics

The *thermal conductivity of vitreous silica* has been determined by inserting a thin optically flat plate of silica between two aluminium rods and establishing a temperature gradient in the composite bar. The correction for the unavoidable temperature drop across the air films between aluminium and silica was as much as 15 per cent., but remained constant: the temperature ranged from 70° to 250° C.

The temperature of non-luminous flames was measured by inserting a platinum wire in the flame and plotting the relation between temperature as measured by an optical pyrometer and heating current through the wire. A second plot is made with wire electrically heated *in vacuo*. The point of intersection of the two graphs will give the temperature of the flame, since at this point the surrounding gas in the flame neither imparts nor abstracts heat.

Further work has been done in designing simplified forms of *steel mercury-vapour pumps for high vacua*: one form will give the highest vacua at speeds of 2000 cc./sec., with a backing pressure of 0·2 mm.: another form works in conjunction with a filter pump.

Measurements of *humidity* have been made, using a glycerine film in equilibrium with atmospheres of varying humidity, by measuring the changes in refractive index. Another method is to determine the change in weight of a thin sheet of cellophane: the gain in weight for a change in humidity from 0 to 100 per cent. is of the order of 50 per cent., with a time lag of one hour. In connexion with refrigeration plants work has been done on the *latent heat of sulphur dioxide* at low temperatures. A sulphur dioxide system was connected to a long spiral of copper tubing and the whole immersed in a water bath. The dioxide evaporated into the spiral and left it in the form of gas at the common temperature of the bath and the syphon. The bath was kept at constant temperature by electrical heating; and by finding the weight of dioxide evaporated and calculating the electrical

energy supplied, the energy required to convert 1 gm. of liquid at a certain temperature and under its own vapour pressure into gas at the same temperature and at atmospheric pressure was ascertained. Thus the latent heat was obtained, subject to a small correction for the expansion of the gas from the initial pressure to one atmosphere. Irregularities in the results were traced to the presence of about 0·5 per cent. of water in the dioxide.

Experiments have been made with the *ball-and-tube flowmeter*, which consists of a vertical conical glass tube in which a sphere is free to move in an upward current of fluid; it was observed that turbulent flow set in above the ball. By using different liquids and gases it was found that, for a given meter, the calibration data for any fluid of known density and viscosity could be computed: with pulsating flow the average rate of flow was given by the mean ordinate of the displacement-time curve rather than the mean position of the ball.

The percentage of carbon dioxide in the air was measured by finding the velocity of sound. Stationary sound waves were produced between a piezo-electric quartz oscillator and a reflecting plate, the positions of the nodes being recognized by the increase in electrical load thrown on the oscillator: the wave-length in the gas could be determined by traversing the reflector from node to node, the nodes being about 8 mm. apart at a frequency of 40,000 cycles.

II. Radiology

The atomic structure of inter-metallic compounds has been determined by X-rays: in the case of AgMg the effect of etching is to dissolve out the magnesium from the lattice, whereupon the silver atoms recrystallize at room temperature on a face-centered lattice. In the case of the K-radiation from copper no trace was found of the J_2 phenomenon, which should occur according to Barkla's work.

For measurement of *X-ray intensity and dosage* there seems to be a possibility of obtaining enough current to record on a pivot micro-ammeter, by using a sealed multiplate ionization chamber containing a heavy gas such as methyl bromide.

III. Sound

The transmission and reflection of sound by partitions has been examined, using a loud speaker excited by a valve oscillator as transmitter, and a microphone and valve amplifier as receiver. In the case of successive partitions of hair-felt, each partition absorbs a constant fraction of the energy incident upon it at frequencies of 1000 cycles: at lower frequencies the fraction decreases as the number of partitions increases. Methods have been devised for testing the *acoustic features of buildings* before construction by means of model sections. The first of these consists in photographing the air disturbance generated in a model section by an electric spark, acting as a source of sound, followed a few microseconds later by a second spark which enables a photograph to be taken*.

In the second method the model outline of the test section is laid on the bottom of a tank of water; a short train of waves is generated within the section by means of an impulse from a plunger, and the waves are reflected from boundaries in a manner analogous to sound waves.

The absolute measurement of sound intensity is being measured by a torsion balance, one arm of which carries a light piston surrounded closely by a reflecting plane acting as a guard-ring. The repulsion exerted by sound waves causes a steady deflection of the piston.

IV. Optics

Photo-electric cells are being used for *spectrophotometric measurement in the ultra-violet*: purification of the light is effected by means of an auxiliary spectroscope. Difficulty has been found in obtaining a steady source of ultra-violet light; the mercury arc is fairly steady, but the number of lines is insufficient, and the tungsten arc is too unsteady. It is intended to modify the apparatus so that fluctuating sources can be employed.

Mathematical work on the *theory of lens systems* has been carried out and communicated to the Optical Society. The formulae for five image aberrations of the first order have been extended to the eleventh order, giving 451 aberrations in all.

The fatigue and adaptation shown by the eye under intense illumination has been investigated in its relation to *visual acuity and the perception of photometric contrast*. This work, in conjunction

* *J. Sci. Instr.* **3**, 1926, 393.

with the development of the *trichomatic colorimeter*, has enabled the Laboratory to give considerable assistance to industries which are interested in colour measurement.

A method has been developed by which the *optical transmission of partially silvered surfaces* can be observed throughout the process of silvering by cathode sputtering. The method is a visual one, utilizing a wedge and rhomboidal prism, and the brightness of the transmitted light is compared with that from a standard source. R. T. B.

(*To be continued.*)

Handbuch der Physik. Band XVII: Electrotechnik. (Berlin: Julius Springer, 1926.) Pp. vii + 392. Price M. 31/50 in paper cover; M. 33/60 bound.

The treatment of the subject of electrotechnics in a volume of this size calls for rigorous pruning of subject matter, and probably two or three volumes would be required for a reasonably complete presentation.

In the first chapter a concise account is given of telegraphy and telephony on wires: the telegraphic equation is discussed and its applications to special cases are given: the fundamental formulae of telegraphic networks and filters are derived. Some detailed descriptions are given of apparatus, such as selector gear in automatic exchanges.

The next chapter treats of wireless telegraphy and telephony in an elementary fashion: the discussion of propagation of waves is hardly up-to-date. X-rays and the applications of electricity to medicine are next described: many types of X-ray tubes and high tension generators are illustrated and X-ray spectroscopy is briefly referred to. The electro-cardiograph is mentioned and reproductions are given of records produced by it.

Medical apparatus used for galvanization, faradization, ultra-violet and heat treatment is described and illustrated, and this section should be of interest to makers of electro-medical instruments.

In the chapter on transformers and electrical machines the main formulae and vector diagrams are derived from first principles. Phase transformers, frequency doublers, resonance transformers, armature reaction and commutation receive notice, and the hunting of alternating current machines is discussed. The operation of synchronous motors is well treated.

A chapter is given to the mercury rectifier, with illustrations, curves and oscillograph records: high power rectifiers are described for currents up to 1000 amperes. The distribution of electricity at high pressures forms the subject of the eighth chapter, and considerable attention is paid to the properties and construction of suitable insulators. Losses due to capacity currents and effects on adjacent low power systems are given detailed treatment.

A fairly extensive account of the problems of switching in relation to pressure and current surges concludes the volume.

R. T. B.

JOURNAL OF SCIENTIFIC INSTRUMENTS

VOL. IV | OCTOBER, 1927 | NO. 13

THE MEASUREMENT OF THE POLARIZATION CAPACITY OF PLATINUM PLATES IN SULPHURIC ACID.

By W. T HEYS, B.Sc. [Under the guidance of ALBERT GRIFFITHS, D.Sc., Professor of Physics at Birkberk College (University of London).]

[*MS. received, 21st January, 1927.*]

ABSTRACT. The paper describes a method of determining the polarization capacity of an electrolytic cell consisting of platinum electrodes in sulphuric acid. Across the cell is placed a condenser of known capacity, and the system is short-circuited. The short circuit is broken and a second condenser of known capacity is charged to a known potential and then discharged into the system. The first condenser is disconnected from the electrolytic cell and from the second condenser and then discharged through a ballistic galvanometer. Hence the potential difference attained by the electrolytic cell, which is the same as that of the first condenser, is calculated. It is impracticable to determine the potential difference from a discharge of the second condenser, because of the residual effects.

The depolarization of the cell is rapid and the potential difference immediately after discharge of the second condenser into the system is deduced by varying discontinuously the time of contact of the cell with the first condenser. The various connexions and disconnexions are made by means of a falling vulcanite plate on which are specially shaped brass plates, which, during the fall of the plate, pass over suitably placed connecting brushes.

That the results obtained mean something definite and are substantially accurate is proved by the determination of certain polarization capacities by (1) a bridge method, using alternating currents provided by triode-valves, and (2) the falling plate method. The values obtained by the two methods are in substantial agreement.

A PAIR of platinum electrodes in sulphuric acid may be considered to act crudely as a leaky condenser. For the purposes of the present paper, the polarization capacity of the electrolytic cell may be defined as the ratio of the quantity of electricity sent into the cell to the difference of potential developed, when the time of charging, and the quantity of electricity, are exceedingly small. Such a cell may crudely be considered to be a compound condenser consisting of two condensers in series, each plate forming a single condenser; and if the electrodes are identical in character the capacity of a single electrode may be considered to be double that of the cell; whilst if one electrode has a capacity very small in comparison with that of the other, the capacity of the cell is approximately equal to that of the electrode of the smaller capacity.

The potential difference between the electrodes of the cell diminishes rapidly with time. In the falling plate method of determining the capacity, with which this paper is principally concerned, the potential difference is determined at small intervals after the charging of the cell, and the maximum potential difference developed by the charging of the cell is deduced by extrapolation.

To confirm the validity of the falling plate method some measurements of polarization capacity were made by an alternating current bridge method, the alternating current, of audio-frequency, being obtained by means of a thermionic valve.

Description of the Falling Plate Method

The electrolytic cell whose capacity x is to be measured has one of its electrodes connected to one terminal of an auxiliary condenser of capacity K, K being small compared with x. A condenser of capacity C is charged to a known voltage E, and its charge shared with the electrolytic cell x and the auxiliary condenser K, so that this auxiliary condenser and the charging condenser acquire a potential difference or voltage equal to the back E.M.F. e of the electrolytic cell, caused by the electricity discharged into it. The auxiliary condenser K is rapidly disconnected from the electrolytic cell and the charging condenser C, and discharged through a ballistic galvanometer G by means of which its voltage is determined. On account of leakage this voltage is somewhat less than e, the exact value of which, as explained in detail later, is obtained by extrapolation. By equating the initial and final charges on the condensers and the electrolytic cell we have

$$C.E = (C + K + x)\, e,$$

whence

$$x = \frac{CE}{e} - C - K.$$

For accurate work it is not feasible to eliminate the condenser K and to use the discharge through the galvanometer of the charging condenser C for the measurement of the final E.M.F. e, because the residual charge left by the voltage E overwhelms the small theoretical final charge $C.e$.

In the apparatus to be described K is kept short-circuited until the moment of charging the electrolytic cell, so that it shows no residual charge at the critical moment. Also, since K is rapidly disconnected from C and the electrolytic cell x, it is unaffected by any subsequent changes in x, or by the development of residual charges in C.

Details of Falling Plate Method

Referring to Fig. 1, one terminal of each piece of apparatus mentioned in the previous section is connected to the electrode "a" of the cell x. Each of the other terminals is connected to a separate conducting brush or contact maker. These brushes, numbered 1 to 5, are mounted on a frame, shown in Fig. 2, so that the points, over which slide the falling plate, are in a vertical plane and have the relative positions shown. In addition, mounted on the same frame, is another brush numbered 6. This is connected to the electrode "a" of the electrolytic cell. What is called the falling plate consists of a block of vulcanite on which are mounted brass contact plates P and Q, of the shape shown in Fig. 1. The space around and between the contact plates is covered with a thin sheet of vulcanite of the same thickness as the contact plates.

The reader will readily understand the working of the apparatus if he will make a copy of the parts of Fig. 1 indicating stationary apparatus on tracing paper or any kind of translucent paper. The plate falls downwards relatively to the brushes. This corresponds to the brushes moving upwards relatively to the plate. If the tracing paper is first placed over the plate Q, it will be noted that the condensers C and K, the electrolytic cell x, and the ballistic galvanometer G are all short-circuited. As the tracing paper is moved upwards, corresponding to the plate falling downwards, it will be seen that when brushes 1 and 2 are over P, C is charged by E (see Fig. 3). A little later brush 1 is over the vulcanite; brushes 2, 3 and 4 are on the contact plate P and thus C shares its charge with x and K; brush number 6 is on the vulcanite; brush number 5 is on the contact plate Q (see Fig. 4).

A little later still brush number 4 is on the vulcanite, and still later brush number 2 moves on to the vulcanite. Shortly afterwards brushes numbers 3 and 5 are both on the plate P and thus K discharges itself through the galvanometer G (see Fig. 5).

In calculating the results a correction is necessary to allow for the depolarization of the electrolytic cell in the interval between the moment of connexion of the left-hand pole of the electrolytic cell with the condensers C and K and the moment of disconnexion.

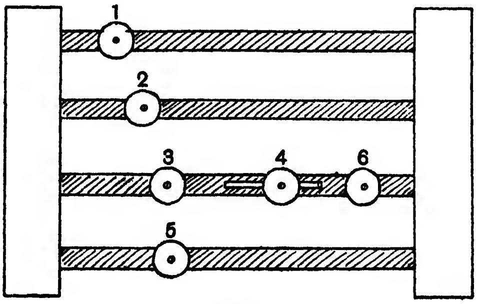


Fig. 2

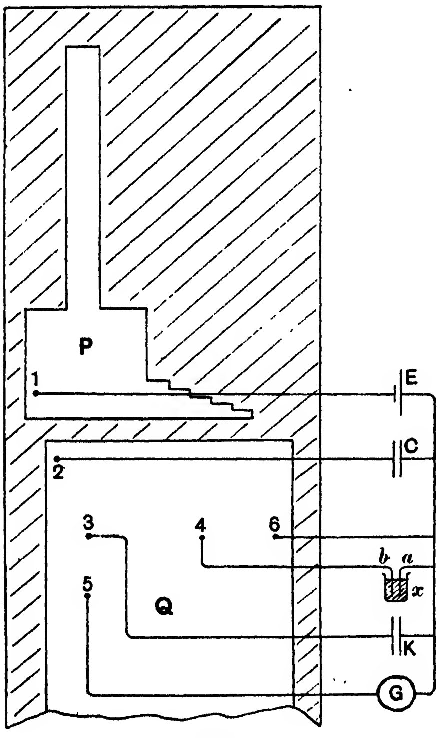


Fig. 1

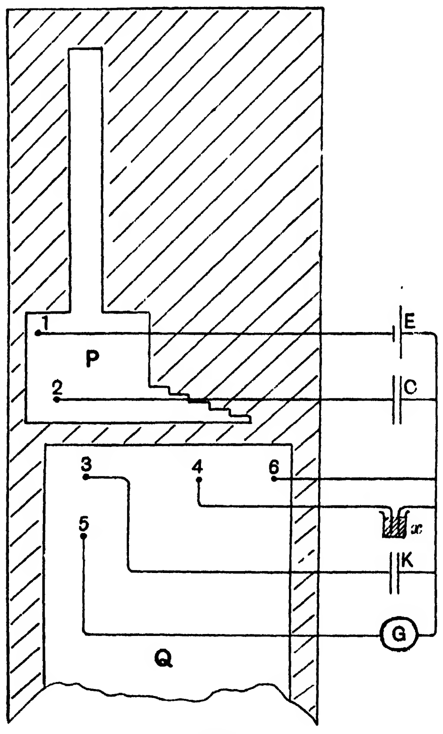


Fig. 3

This interval can be varied by means of brush number 4, which can be fixed in various positions on the horizontal line. On account of the step-like shape of P the interval depends on the position of brush number 4. In this way a number of values of the back E.M.F. of the cell for various small values of the time interval is obtained, and, by plotting the E.M.F. against these intervals, the initial value e may be found for zero interval. It may be mentioned that a calculation, made on the assumption that the resistance at the point of contact between the brushes and the contact plate could be considered to be zero, proved that the time taken to charge x and K is so small as to be negligible.

One difficulty in the work is the development of an E.M.F. in an electrolytic cell when it is left on open circuit. It is found advisable therefore to keep the cell short-circuited as long as possible. To attain this end, there are two brushes (not shown in the figure), mounted on a vulcanite support. These brushes press against a brass plate (not shown in the figure) on the back of the vulcanite plate when it is at rest, and ready for a fall. The brushes are connected one to each electrode of the electrolytic cell x, and thus short circuit it.

The vulcanite plate is loaded with metal and thus becomes so heavy that the friction of the brushes makes no appreciable difference in the velocity of falling.

The plate is allowed to fall between two vertical slotted uprights, lubricated with graphite powder, and firmly supported on a wooden base. There is a hole in the wooden base through which the plate may fall.

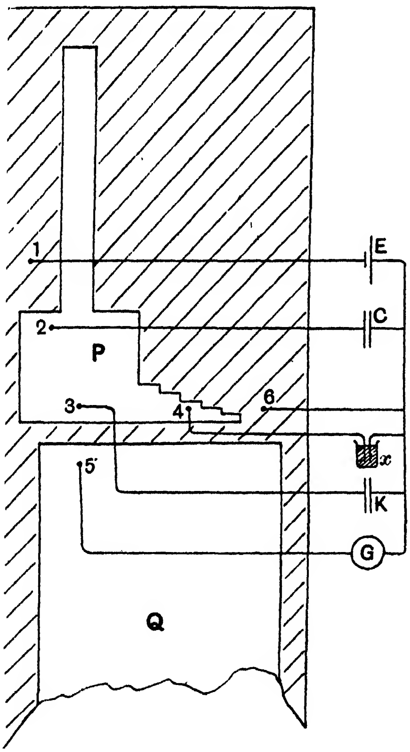


Fig. 4

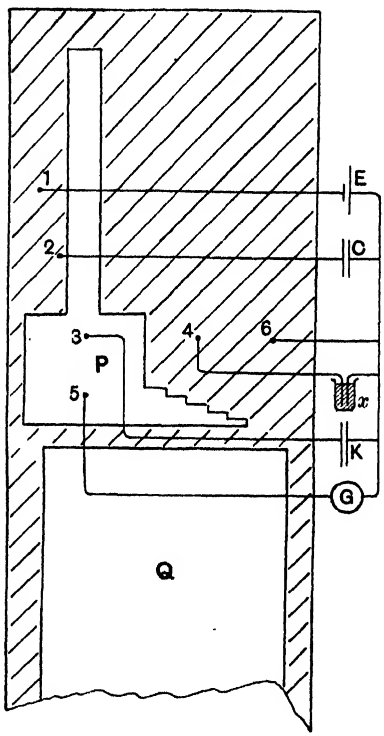


Fig. 5

The brushes are fixed on a permanent framework as shown in Fig. 2. The shaded parts represent vulcanite rods. Brass screw-terminals, each with two or more nuts, are connected to the vulcanite rods. Each brush (not shown in the figure) consists of a thin pointed, bent, strip of brass held in position by the nuts of the screw-terminal. The strip has a longitudinal or vertical slot through which passes the screw of the screw-terminal. This slot in the strip enables a vertical adjustment to be made without much difficulty.

The lateral or horizontal adjustment of brush number 4 is performed by means of a horizontal slot in the vulcanite rod which supports the brush. The framework holding the brushes, numbers 1 to 6, is fixed to the wooden guide, and close to the bottom.

The lower part of the falling plate is situated, before the release of the plate, in the vertical slots of the wooden guides and near the top. Thus the plate falls a big fraction of the height of the guide before the various operations begin.

It was found very soon that discrepancies were present in the results obtained. Tests were made and these showed that when E, the charging battery, was disconnected, a slight deflection was still obtainable and that this was apparently due to some electrical phenomenon which occurred as the galvanometer brush left the brass plate and passed on to the vulcanite. Various means of eliminating this source of error were tried without complete success, and so it was decided to correct for it by the introduction of a "dummy" experiment before and after each deflection recorded ("capacity" deflection).

The intervals during which depolarization took place were obtained by experiment, by discharging a condenser through a suitable high resistance for the period of time to be measured. On measuring the remaining charge in the condenser the time interval of discharge could be calculated.

The long extension at the top of the plate P is to ensure that all the charge on K should pass through the galvanometer G.

Below are some of the results obtained.

Measurement of the Capacity of a cell consisting of Platinum Black Electrodes in Sulphuric Acid.

Size of plates 0·5 × 1 cm.		Times of contact
Charging condenser, 5 mfd. C	(5)	·0027 sec.
Auxiliary condenser, 50 mfd. K	(4)	·0023 sec.
Voltage of C when charged, 2 volts E	(3)	·0018 sec.
Sensitivity of galvanometer, 15 cm. ≡ $\frac{1}{10}$ mc.	(2)	·0014 sec.
	(1)	·0008 sec.

The average corrected deflections were 18·5 cm., 16·18 cm., 15·05 cm., 13·87 cm. and 12·73 cm. for the times 0·0008 sec., 0·0014 sec., 0·0018 sec., 0·0023 sec. and 0·0027 sec. respectively.

A corrected deflection was obtained by observing dummy and capacity deflections alternately, and subtracting the mean of say four dummy deflections from the mean of three alternate capacity deflections.

From the graph (Fig. 6) the deflection corresponding to the back E.M.F. at zero time is 19·8 cm.

$$19{\cdot}8 \text{ cm.} \equiv 0{\cdot}00176 \text{ volt in } K,$$
$$C\,.\,E = (C + K + x)\,e,$$
$$10 = (5 + 50 + x)\,{\cdot}00176,$$
$$x = 5626{\cdot}82 \text{ mfd.}$$

Comparison of Results obtained by the Falling Plate Method with those obtained by an A.C. Bridge Method

In order to check to some extent the accuracy of the results obtained, comparative experiments were performed. In the first case the capacity of two cells was measured by an alternating current bridge method, and then again by the method which has previously been described.

A thermionic valve was connected in a circuit as shown in Fig. 7. A 4-volt battery was connected in series with a resistance, an ammeter and the filament of the valve. The grid was connected to the negative end of the filament through an inductance L_1, across which was connected a variable capacity K_1. An inductance L_2 was connected between the plate and the terminal A. The 100-volt lighting mains were joined to terminal B and the negative end of the filament, the negative side of the mains being towards the filament. In order to produce oscillations of audio-frequency the inductances L_1 and L_2 were each about 0·15 henry. K_1 was a mica condenser of capacity $\frac{1}{8}$ mfd. or of $\frac{1}{12}$ mfd. The frequency

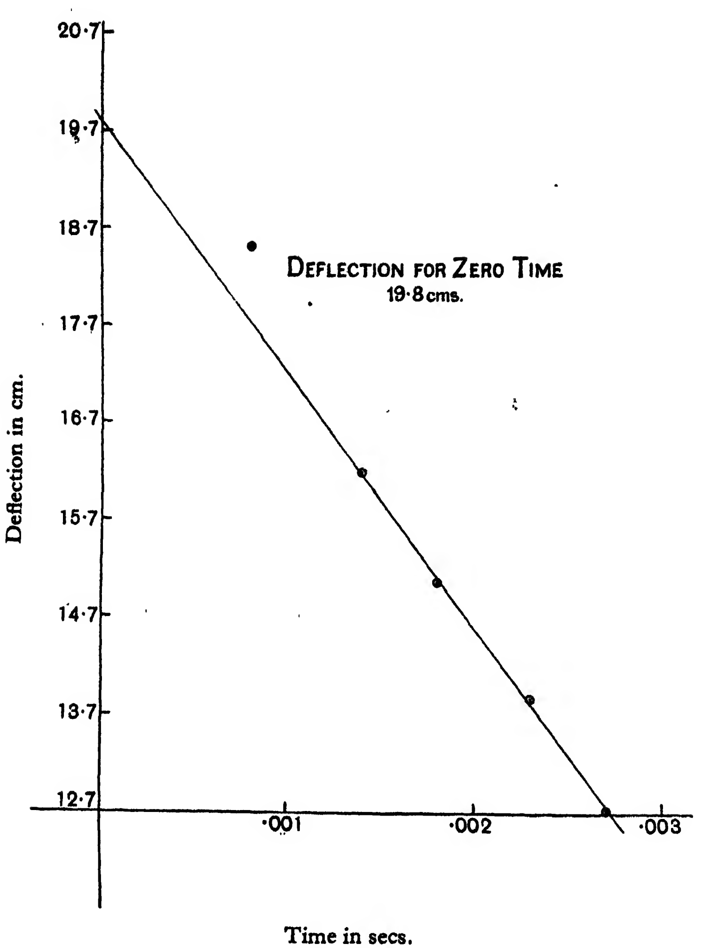


Fig. 6

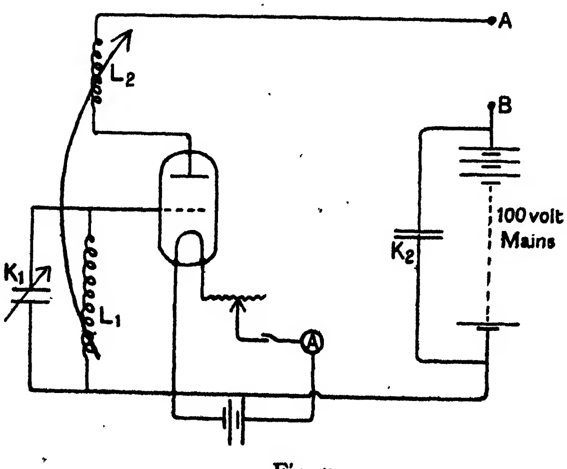


Fig. 7

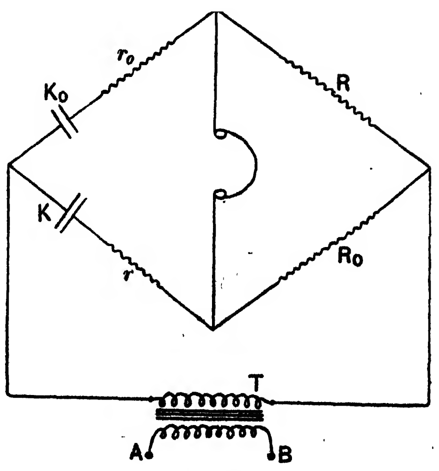


Fig. 8

of the oscillations was therefore 1296 or 1422. The intensity of the note could be varied by altering the closeness of the coupling between L_1 and L_2. A 2-mfd. condenser was connected across the mains to cut down the hum due to the commutator ripple.

This source of alternating current was now applied to an A.C. de Sauty Bridge and two capacities measured. The circuit is shown in Fig. 8. A 10 : 1 step-down transformer T was inserted in the position indicated, which was found to be the best. A pair of 120-ohm headphones was used as a detector.

An absorptive condenser may be regarded, for many purposes, as a pure capacity K in series with a resistance, or as a pure capacity K in parallel with a high resistance. It was decided to use the series bridge in preference to the shunt bridge, by reason of the resistances available.

With this arrangement $K = K_0 \frac{R}{R_0}$, $r = r_0 \frac{R_0}{R}$, where the symbols represent the various capacities and resistances shown in Fig. 8. K_0, being a mica condenser, requires an actual resistance r_0 in series with it, whereas K, being an absorptive condenser, has a resistance r as an integral part of itself.

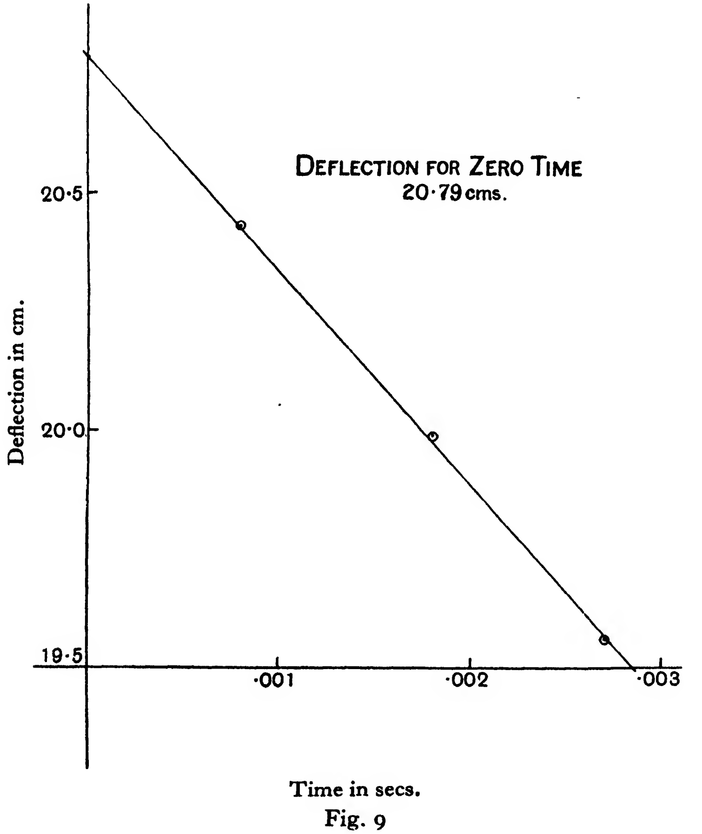


Fig. 9

Results. 1st experiment. Size of plates 1 cm. × 1 cm.

	1	2
K_0	$\frac{1}{3}$ mfd.	$\frac{1}{3}$ mfd.
r_0	38 ohms	38 ohms
R	500 ohms	600 ohms
R_0	18·2 ohms	21·8 ohms
K	9·16 mfd.	9·19 mfd.

$$K = K_0 \frac{R}{R_0} = \frac{1}{3} \times \frac{500}{18 \cdot 2} = 9 \cdot 16 \text{ mfd.}$$

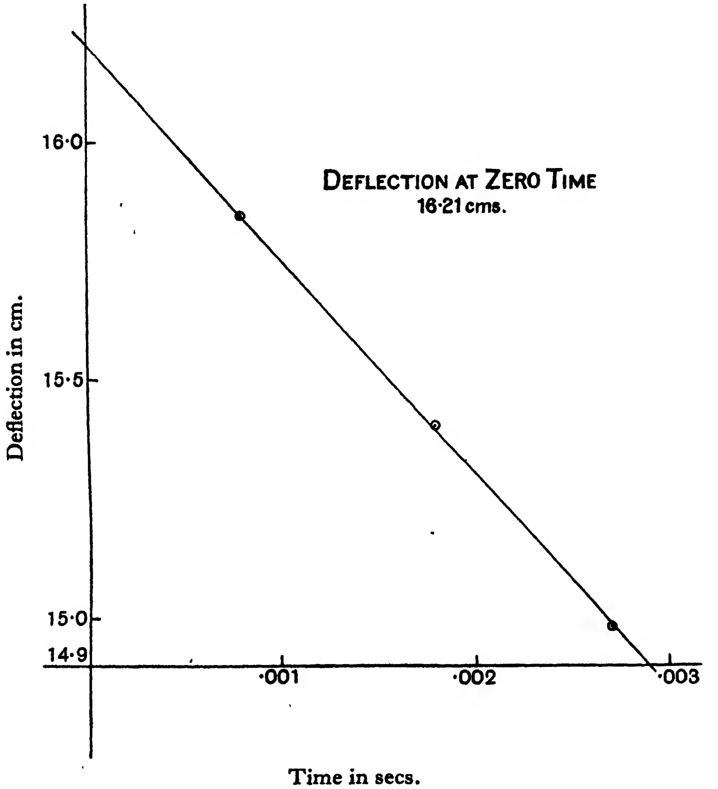
Character of plates: Bright platinum in dilute sulphuric acid.

The sensitivity was such that $\frac{1}{10}$ ohm could be detected by an increase or decrease in the volume of the note in the phones.

Results. 2nd experiment. Platinum wires, of average diameter 0·051 cm., were sealed into glass tubes and the cross-section only exposed. These were thinly coated with platinum black and used as electrodes in a cell, the electrolyte being dilute sulphuric acid. The capacity of this cell was then measured.

	1	2	3
K_0	$\frac{1}{3}$ mfd.	$\frac{1}{3}$ mfd.	$\frac{1}{3}$ mfd.
r_0	170 ohms	160 ohms	140 ohms
R	200 ohms	400 ohms	700 ohms
R_0	69 ohms	134 ohms	240 ohms
K	·966 mfd.	·995 mfd.	·972 mfd.

Average for $K = 0·977$ mfd.



Time in secs.

Fig. 10

Tests were next made using the falling plate apparatus. The results were as follows. (In order to allow the comparisons to be made in as short a time as possible only three variations of time were taken.)

Time	Deflection
1	20·43 cm.
3	19·97 cm.
5	19·56 cm.

From the graph, shown in Fig. 9, the deflection corresponding to the back E.M.F. at zero time is 20·79 cm.

Sensitivity of galvanometer 193·5 cm. ≡ 1 mc.

$K = 2$ mfd. $C = \frac{1}{3}$ mfd.

Since $K = 2$ mfd. if it were charged to a P.D. of 1 volt and then discharged through the galvanometer the deflection would be $2 \times 193{\cdot}5$ cm.

Therefore
$$1 \text{ volt} \equiv 387 \text{ cm.},$$
$$1 \text{ cm.} \equiv \tfrac{1}{387} \text{ volt},$$
$$20{\cdot}79 \text{ cm.} \equiv {\cdot}0537 \text{ volt}.$$

$C \, . \, E = (C + K + x)\, e$, where these symbols have the same meaning as previously.

Then
$$\tfrac{2}{3} = (\tfrac{1}{3} + 2 + x)\, {\cdot}0537,$$
$$x = 10{\cdot}08 \text{ mfd.}$$

In the same way the plates consisting of the cross-section of some platinum wire thinly coated with platinum black were tested and their capacity found.

Results. $C = \frac{1}{6}$ mfd. $K = \frac{1}{3}$ mfd.

Voltage of C when charged = 2 volts.
Sensitivity of galvanometer — 1 mc. ≡ 193·5 cm.

Time	Deflection
1	15·842 cm.
3	15·404 cm.
5	14·984 cm.

From the graph shown in Fig. 10 the deflection corresponding to the back E.M.F. at zero time is 16·21 cm.

The condenser K has a capacity of $\frac{1}{3}$ mfd. so that if charged to a P.D. of 1 volt it would produce a deflection due to a charge of $\frac{1}{3}$ mc.

$$1 \text{ mc.} \equiv 193{\cdot}5 \text{ cm. deflection},$$
$$\tfrac{1}{3} \text{ mc.} \equiv 64{\cdot}5 \text{ cm. deflection};$$

i.e.
$$1 \text{ volt} \equiv 64{\cdot}5 \text{ cm. deflection},$$
$$16{\cdot}21 \text{ cm.} = \frac{16{\cdot}21}{64{\cdot}5} \text{ volts}$$
$$= {\cdot}251 \text{ volt},$$
$$C \, . \, E = (C + K + x)\, e,$$
$$\tfrac{1}{3} = (\tfrac{1}{6} + \tfrac{1}{3} + x)\, {\cdot}251,$$
$$x = {\cdot}828 \text{ mfd.}$$

Comparison of results.

	A.C. bridge	Falling plate
Big bright plates	9·175 mfd.	10·08 mfd.
Tiny platinum black plates	0·977 mfd.	0·828 mfd.

It was not found convenient, with the apparatus available, to determine the capacity of the electrolytic cell with large platinum black electrodes by the A.C. bridge method; but the comparison of results as shown above gives ground for hope that the falling plate method furnishes reasonably accurate results even with very high capacities.

In the case of the large capacity studied in this paper the capacity of the cell is about 5600 mfd. This means that the capacity of each electrode is about 11,200 mfd. As each electrode is 1 cm. × 0·5 cm. the capacity per sq. cm. of the plate used was about 22,400 mfd.

MEASUREMENT OF VERY FINE QUARTZ SUSPENSION FIBRES. By G. A. TOMLINSON and H. BARRELL.

[*MS. received, 23rd May, 1927.*]

ABSTRACT. The paper describes two indirect methods of measurement. One is purely mechanical, and involves a measurement of the elastic strain under a known tension, from which the mean cross-section can be found. The other method depends on the observation of certain diffraction phenomena produced in white light.

In a set of fibres measured, the diameter varied from $3{\cdot}3\mu$ to $0{\cdot}6\mu$. The optical method is found to become unreliable when the diameter falls below about three wave-lengths.

The measurement of fine quartz suspension fibres ranging down to 0·5 micron in diameter requires the application of indirect methods, as it is not practicable to handle the fibre in any way. Methods involving direct optical magnification fail to give results, on account of the small size of the fibres, which is comparable with the wave-length of visible light. Five different fibres, for example, ranging from 0·6 to 2·2 microns all appeared to be of about the same diameter when examined by optical projection at 250 times full size, and the image formed could not be brought into sharp focus. A somewhat larger fibre, 3·3 microns in diameter, was found to focus more sharply, but the resulting measurement was unreliable to the extent of about 20 per cent.

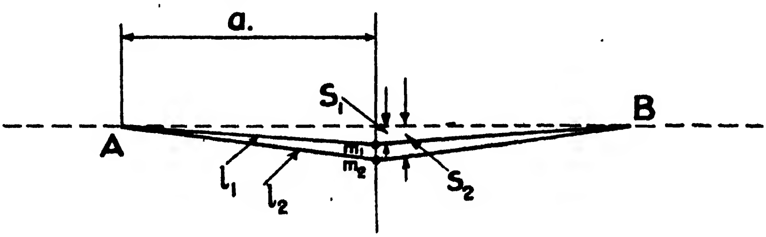


Fig. 1

Two indirect methods of measuring fibres are described in the present paper. One of these is purely mechanical and depends upon a measurement of the elastic extension of the fibre under a known tension, from which the area of cross-section is derived. The fibre is placed in a horizontal direction in the field of an optical projector giving a magnification of 50, and a small wire rider of mass m_1 is hung on to it at its centre. A metre scale AB is then placed horizontally on the screen (Fig. 1) so that the line of action of the force $m_1 g$ bisects the scale, the two end divisions A and B being set in coincidence with the image of the fibre, and the sag s_1 is measured on a short vertical scale. The mass is then increased to m_2 and a second measurement of the sag s_2 made. From these two measurements the cross-section A of the fibre may be derived as follows:

Let T_1 and T_2 = tension of the fibre,
$2l_1$ and $2l_2$ = length of fibre between A and B,
$2L_1$ and $2L_2$ = total length of fibre between supports,
E = modulus of elasticity,
$2a$ = base length = 1000 mm.

Then
$$T_1 = \frac{am_1 g}{2s_1} \quad \text{and} \quad T_2 = \frac{am_2 g}{2s_2},$$

and by similar triangles
$$\frac{L_1}{l_1} = \frac{L_2}{l_2}$$

and
$$\frac{L_2 - L_1}{L_1} = \frac{T_2 - T_1}{AE} = \frac{l_2 - l_1}{l_1}.$$

We may substitute a for l_1, without appreciable error, which gives

$$\frac{ag}{2AE}\left(\frac{m_2}{s_2}-\frac{m_1}{s_1}\right)=\frac{\sqrt{a^2+s_2^2}-\sqrt{a^2+s_1^2}}{a}$$

$$=\frac{s_2^2-s_1^2}{2a^2}$$

or

$$A=\frac{a^3g}{E}\left(\frac{m_2}{s_2}-\frac{m_1}{s_1}\right)\cdot\frac{1}{(s_2+s_1)(s_2-s_1)}.$$

The following table gives the results of the measurement of six fibres, and shows the order of masses and sags required. The latter are given as measured, 50 times actual size.

Table I.

Fibre No.	m_1 gm.	m_2 gm.	s_1 mm.	s_2 mm.	T_1 dynes	T_2 dynes	Tensile stress dynes per sq. cm f_1	f_2	Fibre diameter microns
1	0·00072	0·00178	20·0	27·7	8·8	15·8	4·9 × 10⁸	8·8 × 10⁸	1·51
2	0·00106	0·00394	28·2	32·1	9·2	30·0	1·1	3·7	3·30
3	0·00054	0·00126	30·0	43·3	4·4	7·1	16·3	26·4	0·59
4	0·00106	0·00250	24·6	34·1	10·5	18·0	8·1	14·0	1·28
5	0·00106	0·00250	21·6	27·2	12·0	22·5	3·2	6·1	2·17
6	0·00106	0·00250	20·3	31·7	12·8	19·3	12·0	18·0	1·16

$a = 500$ mm.
$E = 5{\cdot}18 \times 10^{11}$ dynes per sq. cm. (Kaye and Laby) for quartz fibre.
Ultimate tenacity $= 100 \times 10^8$ (Kaye and Laby).

It will be seen that the mass of the riders ranges from about ½ to 4 mg., which are readily obtained as short lengths of fine wire suitably bent. The stress produced in all cases falls well below the tenacity of the fibre. The accuracy of the measurement, apart from errors involved in the assumed value of E, could be made about $\pm$ 2 per cent. by choosing suitable values for the masses. The result obtained is of course an average cross-section of the whole length of the fibre under tension. It should be mentioned that the weight of the fibre is quite negligible in comparison with that of the rider. A fibre of diameter 1μ, for example, has a weight of only $1{\cdot}73 \times 10^{-8}$ gm. per cm. The method is quick in application, all the measurements involved in the above table being made in about 45 minutes.

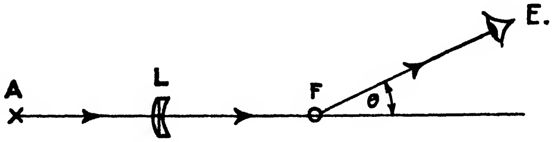


Fig. 2

The second indirect method depends on the observation of certain diffraction phenomena produced when the fibres are placed in a beam of white light. To view the diffraction effects at their best, a parallel beam of white light from a carbon arc is directed on to the fibres, as in Fig. 2. A is a carbon arc situated at the principal focus of a collimating lens L, and F is the section of a fibre whose axis is perpendicular to the plane of the paper. An eye placed at E sees the fibre brilliantly coloured. θ is the direction with respect to the direction of the incident beam in which a certain colour is observed.

If θ is maintained constant and the fibre is displaced along its own axis, the colour usually changes, in some cases passing through a complete spectrum. This indicates a method of examination for variations of diameter, since the diameter can be the only variable factor.

Upon varying θ and looking at the same portion of fibre, the colour changes continuously, the sequence being from shorter to longer wave-lengths in the spectrum as θ increases. In some cases the sequence is traversed two or three times in succession by increasing θ from zero to about 70° of arc. The succession of colours, and their directions as indicated by θ, lie symmetrically about the direction of the incident beam. The most brilliant effects are always observed when the value of θ is small. Systems of fainter colours are viewed when the eye is on the same side of the fibre as the source, *i.e.* looking in the direction of the incident light.

These effects are in general similar to those produced when a fine slit is illuminated with parallel white light. The formula* connecting c, the slit-width, with θ and the wave-length λ for *maxima* is

$$c \sin \theta = \frac{u_n}{\pi} \lambda,$$

where u_n is one of the roots of the equation $u = \tan u$. The roots of this equation are

$$\begin{aligned} u_0 &= 0, \\ u_1 &= 1{\cdot}43\pi, \\ u_2 &= 2{\cdot}46\pi, \\ u_3 &= 3{\cdot}47\pi, \\ u_4 &= 4{\cdot}48\pi, \text{ etc.} \end{aligned}$$

Therefore if θ_1, θ_2, and θ_3 are the directions in which a certain colour, say yellow, is observed, then

$$\begin{aligned} c \sin \theta_1 &= 1{\cdot}43\lambda, \\ c \sin \theta_2 &= 2{\cdot}46\lambda, \\ c \sin \theta_3 &= 3{\cdot}47\lambda, \end{aligned}$$

where $\lambda = 0{\cdot}59\mu$ for yellow light.

The following observations (Table II) of the deviations corresponding to yellow maxima were obtained with a certain fibre. The fibre was mounted at the centre of the table of a large Hilger spectrometer. In place of the telescope, a cardboard screen having a small aperture at its centre was attached to the telescope arm, the position of which was observed on a scale of degrees. The optical system was the same as in Fig. 2. Readings were taken on both sides of the direction indicated by $\theta = 0$.

Table II.

Order	θ_R	θ_L	Mean θ	c in μ
1	15	12	14	3·5
2	33	28	30	2·9
3	46	45	46	2·8
4	58	62	60	3·1
				Mean c = 3·1

Similar results were obtained for some smaller fibres, except that less maxima were displayed. One of the fibres showed no maxima and therefore corresponds to the condition $c = \lambda$ in the theory of the fine slit. Taking $\lambda = 0{\cdot}6\mu$ as the effective wave-length of white light then $c = 0{\cdot}6\mu$ approximately. It should be mentioned that the optical estimates were derived before the mechanical values were known.

In Table III the optical values obtained from observations of both yellow and green maxima are compared with the mechanical values, the latter being arranged in descending order of magnitude. It appears that the two methods are in fair agreement for fibres down to about 2μ in diameter. In other words the "equivalent slit-widths" and the diameters

* Schuster's *Theory of Optics*, 2nd ed. p. 103, or Wood's *Physical Optics*, 2nd ed. p. 201.

are equal, and the fibres act as line sources of small width. Below 2μ the optical method tends to give larger errors as the diameter approaches the dimension of a wave-length.

Table III.

Fibres	Mechanical Values (M)	Optical values (O) $\lambda = 0{\cdot}59\mu$	$\lambda = 0{\cdot}55\mu$	Mean	O–M
	μ	μ	μ	μ	
2	3·30	3·1	3·5	3·30	+ 0
5	2·17	2·2	2·5	2·35	+ 0·18
1	1·51	1·8	1·8	1·80	+ 0·29
4	1·28	1·6	1·8	1·70	+ 0·42
6	1·16	1·8	2·1	1·95	+ 0·79
3	0·59	(0·6)	(0·6)	(0·6)	—

In general the maxima exhibited for small values of θ ($\theta < 10^\circ$) did not fit the theory of the line source. It is probable that they are complicated by interference phenomena produced by rays refracted and reflected by the fibre.

Such an optical examination of a fibre provides a useful preliminary test for uniformity and approximate diameter. For examination of uniformity, it is important to keep θ constant and to displace the fibre along its own axis. The direction of the variation can be interpreted by noting the succession of colours, *i.e.* a change from blue to green indicates an increase of diameter. This test would provide also a very rapid means of comparison with a standard fibre which has been measured mechanically.

When the same portion of fibre is viewed and θ is steadily increased from zero towards $\pi/2$, the number of maxima of the same colour passed gives a rough estimate of the size of the fibre. Yellow maxima are the best to observe. If several maxima are seen, then the diameter is of the order of several microns, if no maxima are seen, then the diameter is of the dimension of a wave-length ($0{\cdot}6\mu$).

The work described in this paper was carried out in the Metrology Department of the National Physical Laboratory, and the authors are indebted to Sir Joseph Petavel and Mr J. E. Sears, Junr., for their interest and permission to publish the results.

A NOTE ON THE USE OF THE COMPTON ELECTROMETER FOR MEASURING CHARGE. By E. G. COX and G. C. GRINDLEY. University of Bristol.

[*MS. received, 28th February,* 1927.]

ABSTRACT. The relation between sensitivity to charge and sensitivity to voltage of the Compton electrometer is discussed. Considerations of a general character indicate that a high voltage sensitivity is not necessarily accompanied by a correspondingly high sensitivity to charge. The results of an experiment are given in which a twenty-seven-fold increase in voltage sensitivity was accompanied by a fifty per cent. increase in sensitivity to charge.

It is well known that the Compton electrometer* has, when suitably adjusted, a sensitivity to voltage far exceeding that obtainable with the ordinary Dolezalek instrument. As the electrometer is frequently used for the measurement of small charges and currents, it appears to be of interest to point out that the sensitivity to charge does not rise very much when the voltage-sensitivity is increased. In order to understand this point, it is necessary to distinguish between the various factors which govern the sensitivity of an electrometer.

* *Journ. Scient. Instr.* **3**, 381.

When a fixed potential difference is applied between the quadrants, the simple theory shows that when the potential V of the needle is large compared with that of the quadrants the sensitivity to voltage is proportional to V. This result is obtained by assuming that the only couple opposing the deflecting couple due to the potential difference between the quadrants is that resulting from the torsion of the suspension. Actually, however, a third couple influences the motion of the needle; this is the distortional electrostatic control, and is due, briefly, to the distortion of the lines of force inside the quadrants as the needle moves. In a symmetrical electrometer this control is positive, *i.e.* tending to reduce the deflection, but by suitably altering the disposition of the needle and quadrants it may be made negative. In this way the total restoring couple may be made as small as we please, with a corresponding increase in sensitivity. This is the basis of the Compton electrometer.

When one pair of quadrants is insulated, as it is when the electrometer is used for the measurement of charge, yet another control is introduced. This, the inductional electrostatic control (first investigated by Sir J. J. Thomson*), is due to a reduction in the effective potential difference between the quadrants caused by the induction of charges on the quadrants by the moving needle. It has the same effect as an increase in the capacity of the electrometer. From the nature of this control it is evident that it is always positive, no matter how the needle and quadrants are situated. Furthermore, it is in general much larger than the distortional control, the sign of which is not therefore of first importance where the measurement of charge is concerned. It can be shown† that when a charge q is communicated to an electrometer whose needle is at a potential V, the deflection is given approximately by

$$\theta = \frac{k_1 V q}{c\left[k_2 + k_3 \dfrac{V^2}{C} + k_4 V^2\right]},$$

where c is the capacity of the electrometer and any connected system when the needle is undeflected.

The terms k_2 and $k_3 \dfrac{V^2}{C}$ are positive and represent the mechanical and inductional controls respectively. The term $k_4 V^2$, representing the distortional control, may be either positive or negative. In the case of the Compton electrometer the value of $k_4 V^2$ is adjusted to be slightly greater than $-k_2$; the term $k_3 \dfrac{V^2}{C}$ disappears for a constant potential difference between the quadrants and consequently the deflection for a small P.D. is very large. If, however, one pair of quadrants is insulated, the term $k_3 \dfrac{V^2}{C}$ is, unless c is very large, still finite, so that, although we may have $k_2 + k_4 V^2 = 0$, the sensitivity is nevertheless comparatively small.

It might seem that it would be possible, by making the distortional control sufficiently negative, to reach the state when

$$k_2 + k_3 \frac{V^2}{C} + k_4 V^2 = 0,$$

and thereby to obtain a very large sensitivity to charge. Actually, however, if $k_2 + k_4 V^2 < 0$, the needle is unstable, so that the sensitivity is limited by this condition.

In the case of the Compton electrometer it is possible to calculate the induction control in terms of the geometry of the instrument, and it is found that when the conditions for infinite voltage sensitivity are satisfied, the sensitivity to charge is still finite.

* *Phil. Mag.* (1898) 536.

† Cf. Makower and Geiger, *Practical Measurements in Radio Activity*, ch. I.

The writers have carried out some experiments to find how the sensitivity to charge of the instrument, as supplied by the Cambridge Instrument Company, increases when the sensitivity to voltage is made very high. The sensitivity to charge was measured by connecting one plate of an air condenser (capacity about 1 cm.) to the electrometer, applying a measured voltage to the other, and determining the deflection under various conditions of adjustment.

The following table gives the results of some determinations of sensitivity for different quadrant settings. The numbers in the first column are readings on the micrometer attached to the movable quadrant. The second column gives sensitivity to voltage in mm. per volt, while the third gives sensitivity to charge in mm. per volt applied to the condenser. These last figures give, of course, only a comparative measure of the sensitivity.

Quadrant reading	S_V		S_C
0	2375		35·5
1	2450		36
2	2500		36·5
3	2925		37
4	3575		38·5
5	4450		41
6	5575		43·5
7	14000		47
8	60000	approx.	55·5

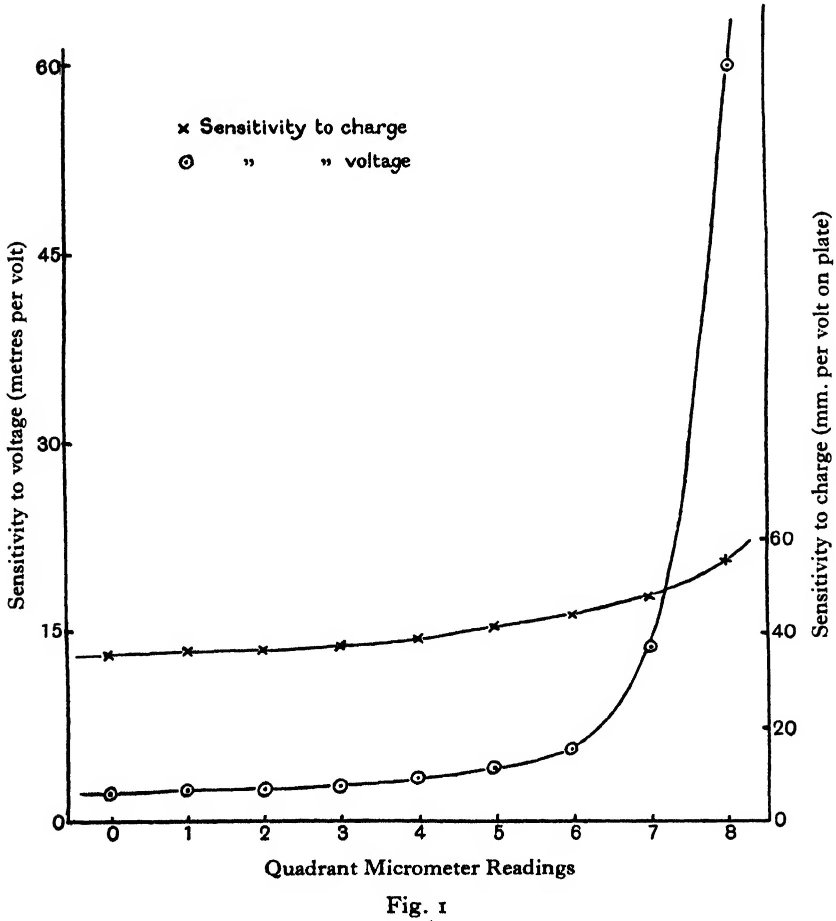


Fig. 1

These results are shown graphically in Fig. 1. Just beyond the micrometer reading 8 the needle became unstable. It will be seen that an increase of nearly thirty-fold in the voltage sensitivity is accompanied by an increase of only 60 per cent. in the sensitivity to charge.

In conversation with Professor K. T. Compton recently we learnt that in his laboratories the instrument is most commonly used as a voltmeter. Where it is used for measuring small charges the electrometer is of very small dimensions (about one-third of the linear dimensions of the Cambridge pattern), and it is connected to an apparatus of relatively large capacity. Under these conditions the induction control is, of course, of less importance than in our experiments.

It should be noted that the electrometers made by the Cambridge Instrument Company differ from those used originally by A. H. and K. T. Compton in the method of obtaining the tilt of the needle. In the latter the rod carrying the mirror is inclined to the needle; in the Cambridge form this rod is perpendicular to the needle, and the tilt is obtained more conveniently by the use of the levelling screws in the base of the instrument. The motion of the needle is, consequently, different in the two cases, but the results obtained with the Cambridge instrument indicate that no essential difference in operation is caused by the change.

We may add that although the difference in sensitivity to charge between a Compton and a Dolezalek electrometer is much less than that suggested by their relative sensitivity to voltage, the Compton instrument is far more satisfactory in practice than the Dolezalek for measuring small currents. This is due partly to the fact that the needle takes up its final position far more rapidly in the Compton instrument and partly to its lower capacity.

A LABORATORY INSTRUMENT FOR ILLUSTRATING NAMES AND NOTATION FOR CONNEXIONS BETWEEN DIALS. By T. C. J. ELLIOTT.

[*MS. received, 12th February, 1927.*]

ABSTRACT. A simple laboratory instrument is described for teaching the principles of correspondence between the readings of inter-connected dials; and its uses are indicated.

If we were to set out on a table a number of different pieces of physical apparatus and try to take a composite photograph of them, after the manner of Francis Galton, probably the only feature in common which would emerge would be graduated dials. If also we exert our imagination to the extent of supposing a composite moving picture to be taken of the proceedings of different physicists (an impossible operation of course), probably the only acts in common which would emerge would be the reading and recording of relations or connexions between the readings of dials.

Let us suppose now that we use our imaginary photographs to construct a composite physical apparatus. This apparatus will consist presumably of a number of dials, but the dials will exhibit no property except that of possible connexions with each other; and, in order to make use of the composite moving picture, it must be possible in some way to discover these connexions experimentally, by practical work with the apparatus. The dials must not show definite quantities such as temperature, or voltage, or time, because, owing to the diversity of the quantities measured in the laboratory, such quantities could not

appear clearly in the composite photograph. Also, though it is natural to use mechanical means, such as belts and pulley wheels, to produce connexions in our composite apparatus, yet this mechanism must be kept out of sight, for owing to the great diversity of causes producing connexions in the laboratory, none of them could manifest itself clearly in the composite photograph.

We conclude then that the composite apparatus must consist of a number of dials mounted on one side of a board, but with the mechanism out of sight on the other side. The student sees a number of dials, something like the switchboard of a power station, but he is forbidden to go behind the board. Unlike the switch board, however, each dial is furnished with a handle for turning the pointer, and also with a clamping arrangement to lock it immovable

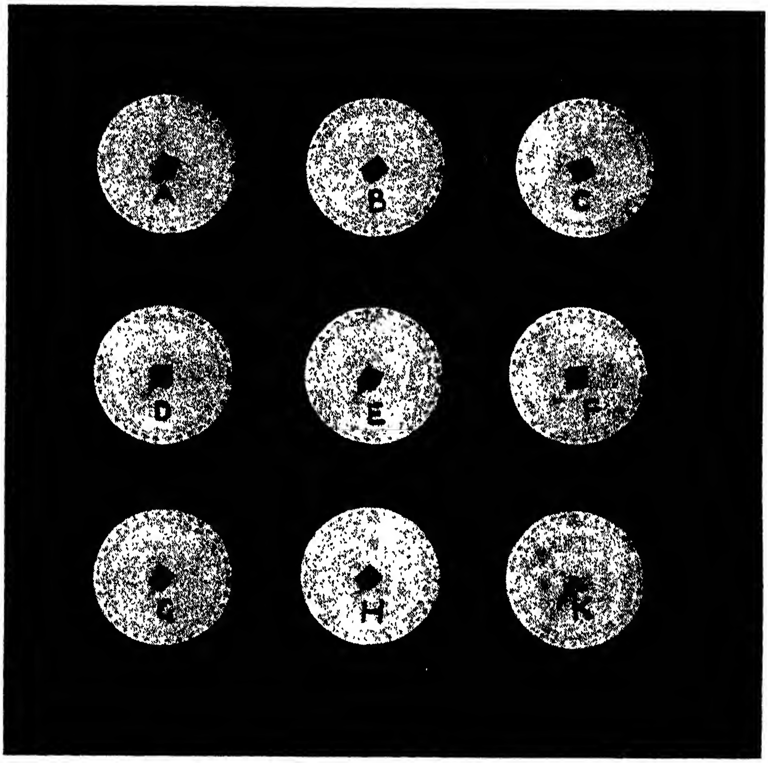


Fig. 1. View of Front of a Small Dial Machine

if required. The use of the handles and clamps is to allow the student to discover experimentally the connexions, for that is the composite practical work proposed for him. For example, if he wishes to discover whether two dials have a one-to-one correspondence, he locks one, and tests whether this prevents the other from moving. The connexions, or as they might be called, the *laws* of the apparatus, are fixed beforehand by the teacher, and when they have been discovered, he can go behind the apparatus and make new laws for the next exercise. So much for the testing of the connexions; as for the recording of them, when found, each dial bears a conspicuous capital letter to distinguish it, and we suggest that these letters should be used to write simple formulae in a manner described below, such formulae being intended primarily as a shorthand to describe what has been discovered.

Figs. 1 and 2 show the front and back of a small model of the apparatus, which I called a "Dial Machine," exhibited before the Mathematical Association. The view of the front

shows nine rotatable cardboard dials, each with a fixed metal pointer at the side, and each bearing a capital letter, but does not show the clamping arrangement, or handle for turning.

The view of the back shows removable pulley wheels of various sizes fixed on the dial shafts, and connected, as desired, by pieces of elastic having hooks and eyes at the ends. The pulley wheels can also be connected, when desired, to the pulley wheels of the mechanisms for giving one-to-two correspondence, two of which are shown in the lower left-hand corner of the apparatus, and which consist of ordinary epicyclic or differential gears for giving the sum or difference of two rotations. Each mechanism consists of three toothed wheels, which I will refer to as A, B and C (Fig. 3), each wheel actuating a pulley wheel.

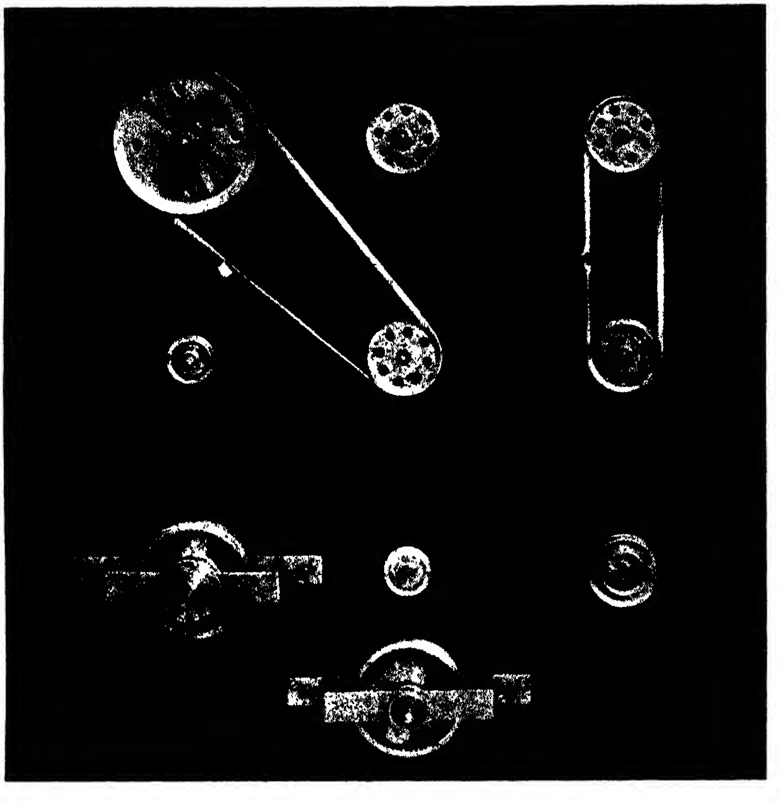


Fig. 2. View of Back of the Dial Machine

B rolls on the rim of A, and C has a projecting flange with teeth on the inside which engage with those of B: thus B rolls on the flange of C as well as on the rim of A. The path of the centre of B, as well as the wheel C, are concentric with A. When A is locked, the motions of the centre of B and the motion of C stand in one-to-one correspondence. When the centre of B is locked (but B can still rotate on its centre), the motions of A and C stand in one-to-one correspondence. Finally when C is locked, the motions of the centre of B and the motion of A stand in one-to-one correspondence.

One-to-three correspondence may be produced by taking two of the above mechanisms and making any dial of the first three solid with some one dial of the second three; for two one-to-two correspondences which have a dial in common (a wheel of one made solid with a wheel of the other) furnish a one-to-three correspondence between the remaining four dials. This method could be extended to higher connexions, if it was worth while.

I need not here go into the manner of systematically testing the connexions, because it is described in a booklet on the apparatus which is still on sale*.

Among the advantages which it is suggested the apparatus may have are firstly, the obvious one that all schools cannot afford a physical laboratory, but that such a miniature or artificial laboratory, costing only a few pounds, demonstrates some of the main features of practical laboratory work. Secondly, that it may be convenient to the teacher to be able to bring this miniature laboratory into his classroom, and use it as the text for a sermon on elementary mathematical physics, undisturbed by the electrical, thermal, and other manifestations which, in a real laboratory, would distract the attention of his class from the vital subject, that of *connexions*. Thirdly, the apparatus lends itself (as I think) to the teaching of composite *mathematics*, that is to say, to teaching those features which a *mental composite photograph*, or impression of different branches of mathematics, would reveal.

To discover these features, we must ask ourselves what mathematical ideas occur again and again in different branches, and form a more or less unchanging background in contrast

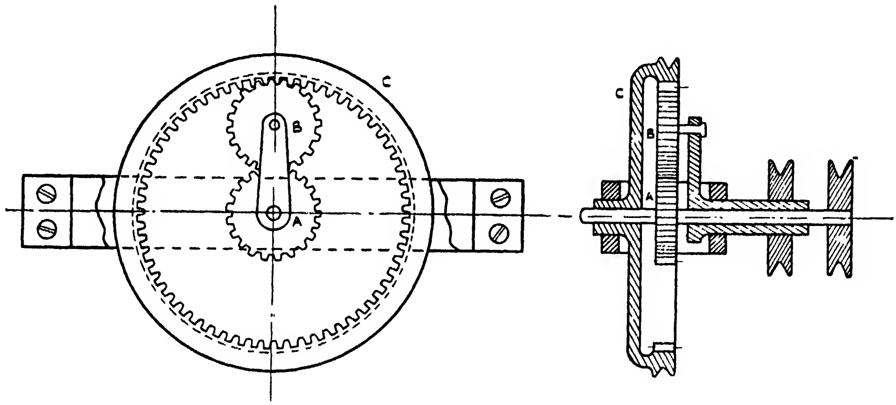


Fig. 3. Epicyclic Differential Gear for One-to-Two Correspondence

to other minor and varying ideas. Two ideas have, in modern times, been recognized as having this kind of special importance, namely the function concept, and the concept of a manifold, and school mathematics seems to be gradually adjusting itself so as to give due weight to these two ideas. The dial machine is peculiarly adapted to emphasizing their fundamental character, and the part of the apparatus is to explain mathematical ideas, not to serve as a calculating machine, as some teachers appear to have thought.

The dial machine explains functions as connexions between dial readings, and manifolds as the absence of connexions. For example, if two dials are found to have a one-to-one correspondence of their readings, I call this indifferently a function or a line in a "space" of two dimensions or "two-fold," and, if there is no such connexion, I call the totality of readings of the two dials the two-fold space. Since a dial plays the part of an axis of co-ordinates in Cartesian geometry, it will probably be needless to point out that, just as by a "space" of two dimensions is meant all the readings of two unconnected dials, so, by a "space" of three dimensions, or "3-dial," is meant all the readings of three unconnected dials, and, by a "space" of four dimensions, or "4-dial," all the readings of four unconnected dials, and so on.

As already said, a one-to-one connexion between two dials is naturally called a *line* of "2-connexion" because two dials are involved. Similarly, a one-to-two connexion between

* *The Dial Machine*, by T. C. J. Elliott. Published by Peterborough Press, Cross Street, Peterborough. Price 4*s*. 6*d*.

three dials is called a *surface* or "3-connexion." Its practical characteristic is that, on locking any one of the three dials, the other two have a one-to-one connexion.

The use of numbers attached to the word connexion, though convenient, is open to the objection that we can have a line, surface, etc., in a space of n-dimensions, in which case the number of dials involved is greater than the number attached to the word connexion. But then the dimensions taken in *sets* of two, three, etc., as the case may be, exhibit the type of connexion indicated by the number attached.

A *point* in a space is a simultaneous set of readings of the dials concerned. A line is *straight* when the ratio of corresponding changes of the dials concerned remains constant. A surface is a *plane* when, on locking any one of the three dials, the connexion between the other two is a "straight line." I need not go further into such definitions, as they are explained in the little book already referred to.

So much for the language used to describe connexions. As for the notation, we naturally make use of the capital letters on the dials as a shorthand to write down the results of our experimental enquiry. If, for example, three dials, A, B and C, form a space, we represent this space by ABC, and, if they are found to form a surface, we represent this fact by enclosing the letters in a bracket and writing (ABC). If it is necessary to distinguish between different surfaces, we must do so by affixing signs to the brackets. As already said, in describing connexions, we are to a large extent free to use either algebraic or geometric language, and which to employ is a nice question of mathematical etiquette.

This freedom is also seen when we consider the linkage of connexions by having dials in common. The simplest example is the two formulae (AB) and (BC). On the one hand, we can bring our algebraic knowledge into play, and say that the *product* of the two functions (AB) and (BC) is the function (AC). On the other hand, we can direct our attention to the fact that the two formulae define a line in the space of three dimensions ABC. There is but one reality, the linkage of connexions, but we elucidate it by drawing our language from two sources.

As said above, school mathematics is already tending to group itself round the ideas of function and of manifold, and it is hoped that the dial machine may hasten the process by providing practical illustrations of both and of the language associated with them.

NEW INSTRUMENTS

THE COX SELENIUM MAGNIFIER

From Messrs H. W. Sullivan, Ltd., we have received a very interesting pamphlet on Mr K. C. Cox's selenium magnifier, which has been developed into a most valuable device for the magnification and increase of speed of cable signals. In order to compensate for the distortion of the cable, curbing combinations of condensers and inductive shunts are employed with the receiver, which sharpen the impulses at the expense of their strength; and to make the best use of such devices the current is reduced to such an extent as to need magnification, which is effected in this case by passing it through a moving coil galvanometer of somewhat short period, the light from which moves over the surface of a large multiple selenium cell connected in bridge fashion.

The form of cell shown in Fig. 1 has 24 pairs of sections and 16 square inches of selenium surface. Its connexions are shown in Fig. 3. For simplicity the connexions of the cell are shown diagrammatically in Fig. 2, in which four sets of pairs of selenium strip sections are shown as if separated, the strips of each section being merely connected in parallel.

A 100 c.p. pointolite lamp and projector causes four rectangular bands of light to be focussed on the selenium cell, each band being parallel to and central with a pair of

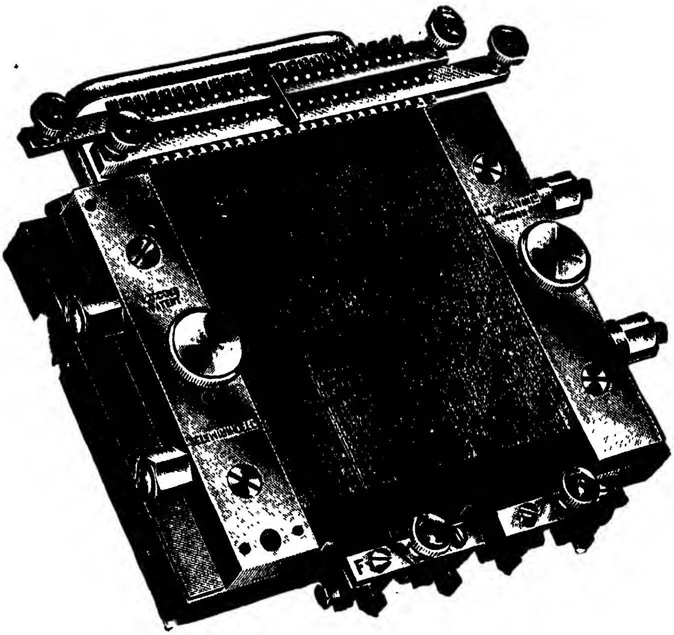


Fig. 1. The selenium cell

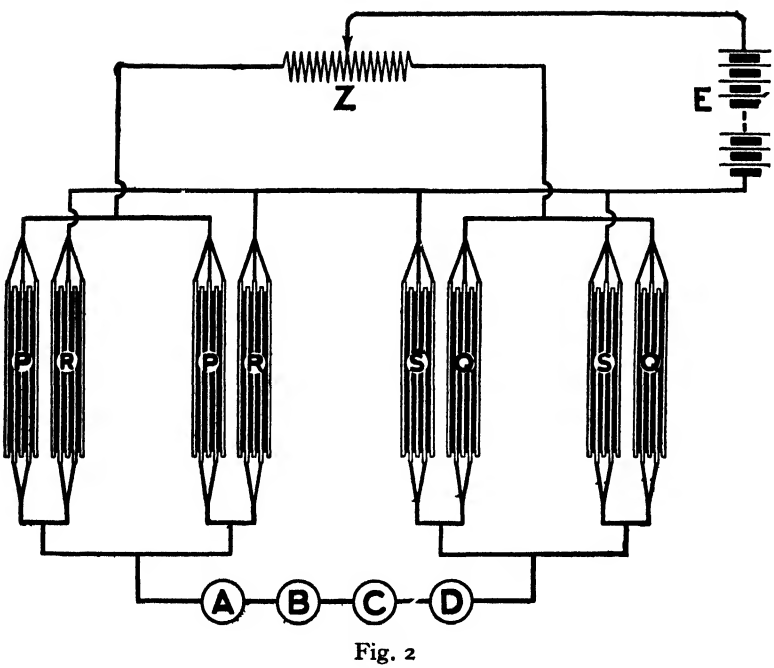


Fig. 2

elements *P* and *R*, so that when the receiving galvanometer is at zero each element is half illuminated. When the bands are moved to the left by the mirror of the signal deflected galvanometer, the elements *P* and *S* are more, and the elements *R* and *Q* less illuminated, thus disturbing the balance of the bridge, and causing current to flow through the

instruments A, B, C and D, which may be a syphon recorder, a re-transmitting relay and an automatic contact device for adjusting the slide of the rheostat Z, which keeps the zero constant.

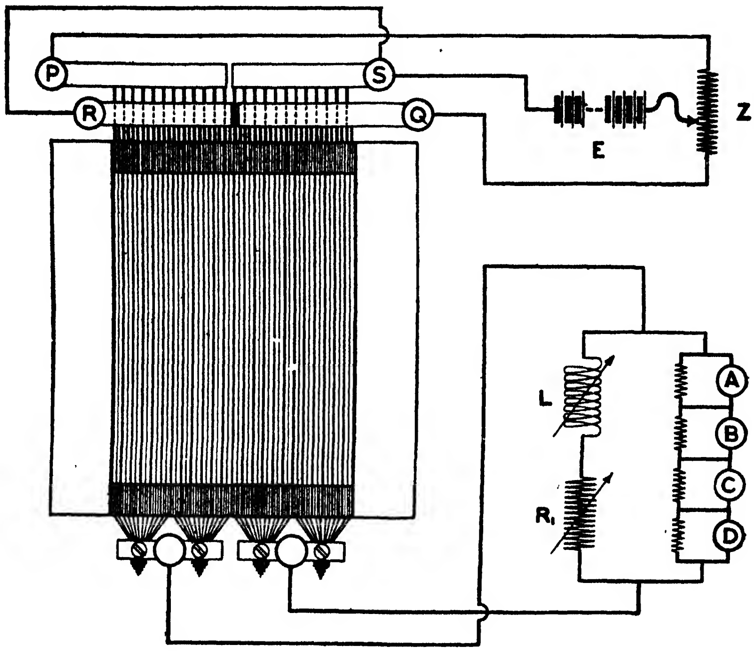


Fig. 3

Fig. 4 shows the rise and fall of the current with no shunt, Fig. 5 with the shunt correctly adjusted, and Fig. 6 with the time constant of the shunt adjusted intentionally to be greater than that of the cell in order to produce "overshooting" at each make and break for strong and clear relay working.

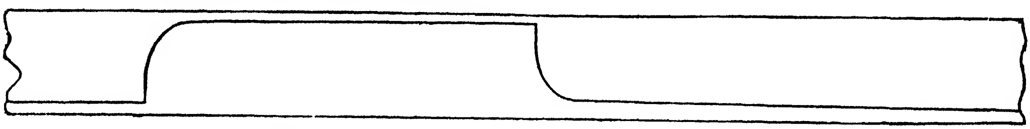


Fig. 4. Current-time curve: no magnetic shunt

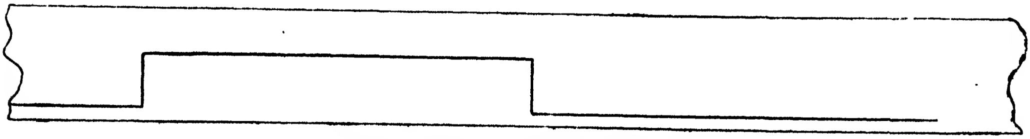


Fig. 5 Shunt correctly adjusted

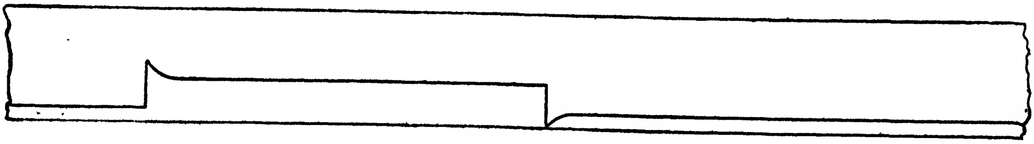


Fig. 6. Time constant of shunt greater than that of cell

THE PENDULUM HARDNESS TESTER

THE great importance of hardness testing has become increasingly appreciated of late years, and the pendulum form of hardness tester introduced by Messrs Edward G. Herbert, Ltd., of Atlas Works, Levenshulme, Manchester, of which they have sent us a description, has the advantage over the ordinary Brinell method of requiring no microscopic examination and measurement. As in the Brinell test, the surface to be tested is indented by a small steel or diamond ball under a known load, but in this case the load is a compound pendulum weighing 4 kilograms, and having a periodic time of something over 10 seconds when the ball is rested on a very hard substance. Fig. 1 shows the pendulum resting on a specimen held in the universal ball vice which the firm also supply.

Fig. 1. Pendulum hardness tester

The cup-shaped indentation produced by the pressure causes the periodic time of the pendulum to be reduced by the control introduced by the rolling of the ball up the sides of the cup, so that the softer the material the shorter the periodic time. In order to obtain the hardness of a material the ball of the pendulum is simply rested on it and the time in seconds for ten swings is measured. This is called the "time hardness number" of the material, which, when multiplied by ten is said to give, for hardened steels, the Brinell hardness number. The time hardness numbers, using a 1 millimetre steel ball, are: glass 100, very hard carbon steel 75, hard carbon steel 65, heat treated alloy steel 52, annealed high speed steel 26, mild steel 20, rolled brass 15, soft cast brass 11 and lead 3.

A special feature claimed for this device is the facility by which the increase of hardness by working, or "induced hardness," can be determined, by simply observing the periodic

time for a number of swings until it attains a maximum and begins to decline. As an example, for a specimen of mild steel:

Passes of ball	0	2	4	6	8	10	12
Time hardness	21	30	30·8	30·9	31·2	32·3	31·6

The maximum induced hardness was therefore 32·3, or 323 Brinell, after 10 swings of the pendulum; and this figure is claimed to be of great value in determining the machining and wearing properties of the material.

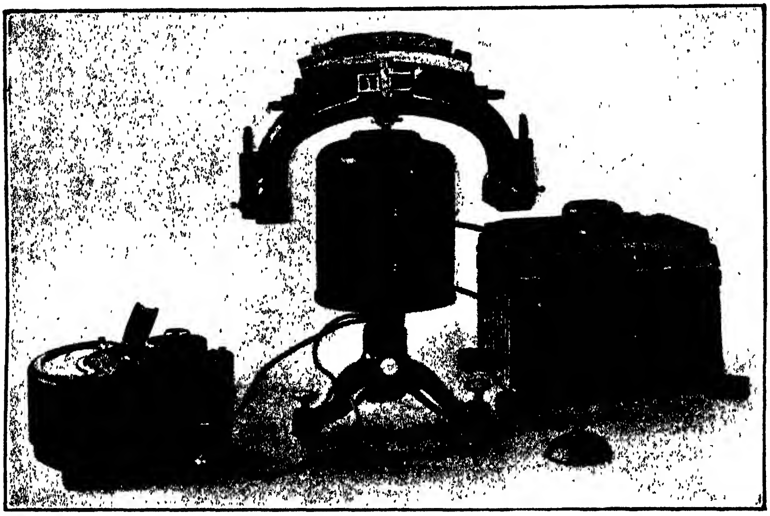


Fig. 2. Showing arrangement of electric furnace and pyrometer for hot hardness testing

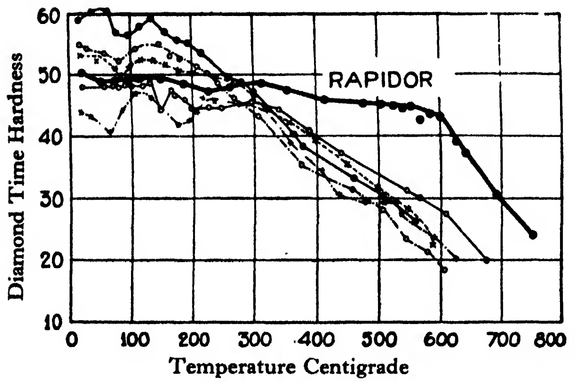


Fig. 3. Hot hardness curves of "Rapidor" and other saw blades

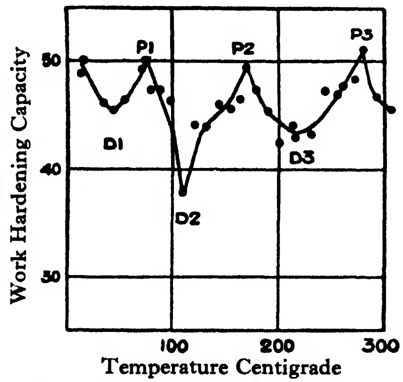


Fig. 4. Temperature-work-hardening curve of Vickers' test bar steel

Hot hardness tests can also readily be made by enclosing a rod of the material in an electric furnace, with a pyrometer (Fig. 2), the upper end of the rod being just exposed for the pendulum to rest on. Figs. 3 and 4 show temperature-hardness curves of various saw blades and a temperature-work-hardening curve of a specimen of Vickers' Test Bar Steel.

The pendulum can be supplied either with a 1 mm. steel ball for occasional work, or with a spherical faced diamond for routine testing, and also with a stand for rapidly raising and lowering it on to a series of specimens, the timing watch being fixed on the stand.

ELECTRICAL DISTANCE THERMOMETERS AND PYROMETERS

FROM Messrs Siemens Brothers and Co., Ltd., of Woolwich, we have received pamphlets No. 825A and 840A and leaflet No. 2050, relating to their electrical distance thermometers and pyrometers of the resistance and thermo-junction types. As regards the former, silk covered nickel wire, wound in spiral form on a porcelain bobbin and varnished and baked, is used for temperatures up to and about 100° C., and bare platinum wire on a mica former for temperatures up to 500° C. A large variety of thermometer casings are made for different

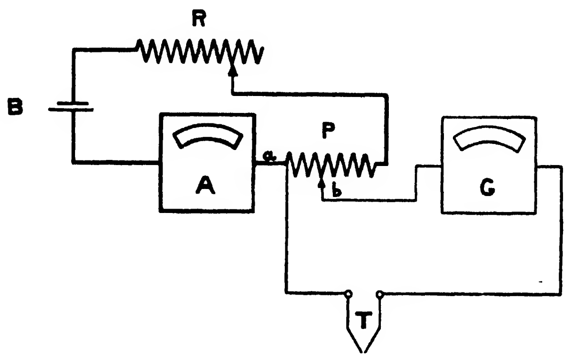


Fig. 1

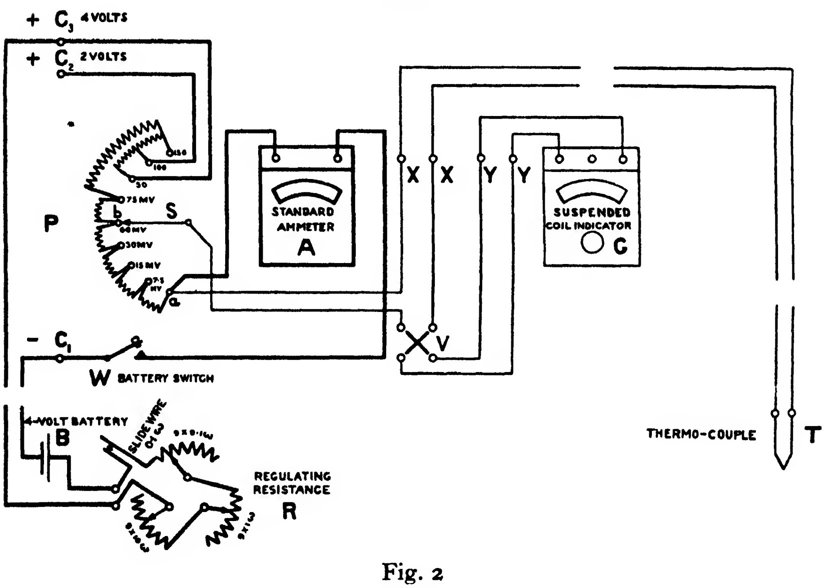


Fig. 2

applications; air and tank temperatures, steam pipes, etc.: one interesting form being intended for taking the temperature of flat surfaces, and consisting of a small circular copper disk having a flat nickel coil immediately behind it.

The indicators are of the moving coil pointer galvanometer type, and are usually mounted either in a cast-iron watertight case, with a robust form of selector switch, or in a dust-tight case with ten change-over switches, allowing any one of twenty thermometers to be connected to the indicator. A portable indicator for either two, four or six thermometers, and two types of recorders of the drum and continuous roll patterns are also supplied;

and an illustration is given of a 648-way switchboard and temperature indicator which has been made for a large granary.

Figs. 1 and 2 show the connexions of a special form of thermo-electric potentiometer which has been designed for measuring the E.M.F.'s of thermo-couples, in which the thermo E.M.F. is balanced by varying the current through a resistance P, which may have a number of convenient values, so that the E.M.F. is a simple multiple of the current indicated on the milliammeter A.

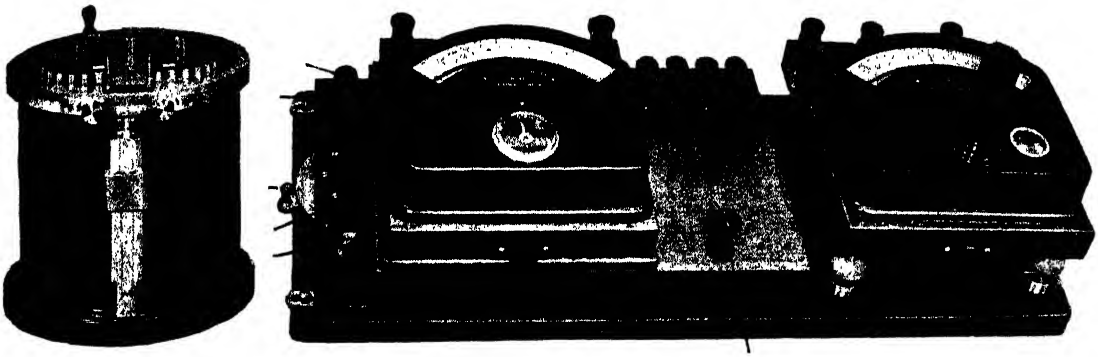


Fig. 3. Thermo-electric potentiometer outfit

The galvanometer is of the suspended coil type, and is calibrated to 5 millivolts on each side of zero, so that readings may be obtained either by completely balancing and reading the milliammeter, or by adjusting the current to the nearest convenient value and reading the residual E.M.F. on the galvanometer. The complete testing outfit is shown in Fig. 3.

LABORATORY AND WORKSHOP NOTES

LOCKING SCREWED MEMBERS

THE case frequently arises in instrument design where one member has to screw into another without risk of its slacking out again. The simplest method of ensuring that the two will lock together is to provide a shoulder on the one which will screw down on to a corresponding facing on the other when the two members are assembled, the two jamming together when screwed up tightly.

Whether they can be locked in this way or not depends on the diameter of the shoulder, the form and helix angle of the thread, and the coefficient of friction. Experience with threads of the ordinary Whitworth form shows that, roughly, the condition that the two members will jam together is given by the formula

$$\text{Diam. in inches} \times \text{Turns per inch} > 72.$$

For example, if the threaded members are 3 inches diameter and are screwed 30 turns per inch, they can be jammed by screwing them together tightly: if, however, they are screwed 18 turns per inch, they cannot be locked, however tightly they may be screwed up.

THE TAYLOR-HOBSON RESEARCH LABORATORY,
LEICESTER.

A METHOD OF OBTAINING MONOCHROMATIC LIGHT.

By J. DICKSON HANNAH, M.Sc.Tech., A.I.C.

It is frequently desirable to obtain a constant source of monochromatic light of some intensity. A simple and effective method consists in passing the gas supply to an ordinary bunsen burner through the apparatus described below.

A large boiling tube or small flask is fitted with a stopper and inlet and delivery tubes extending nearly to the bottom, and is filled to a depth of about an inch and a half with soda ash which has been dried at 110° C. in the air bath and ground to a fine powder. The inlet tube should be sunk about half an inch into the powder, and the outlet should just clear its surface.

When the gas is turned on and the tube tapped lightly, powder will be blown through the burner and give a steady sodium flame. The supply of powder is maintained by the constant slipping of the crater formed round the inlet tube, and will continue satisfactorily for half an hour or longer at a time. The outlet tube should be vertical for about eight inches above the surface of the powder to ensure that particles large enough to choke the burner are not carried over. It is found that commercial soda ash is the most suitable substance to use, as it forms a powder which flows freely and does not cake or jam in the tube. It should pass a sieve of 120 mesh.

LA VÉRIFICATION DES PRISMES À TOIT.

Par A. Biot, Docteur en Sciences Physiques.

Dans un prisme à toit, l'angle du toit ne peut en général différer de 90° que de quelques secondes. Cette précision ne peut être atteinte que par des retouches à la main effectuées prisme par prisme, en même temps que l'on suit l'avancement de la correction de l'angle à l'aide d'un dispositif convenable.

L'instrument employé dans ce but est généralement une lunette de grossissement approprié à l'aide de laquelle on vise, à travers le prisme, une ligne lumineuse très fine parallèle au plan de symétrie du toit; le plus souvent la correction doit être poussée suffisamment loin pour que l'image de la fente soit unique. Or, on trouve fréquemment que l'amplification de l'erreur du toit obtenue par cette méthode est à peine suffisante pour effectuer la correction dans de bonnes conditions. On *double* cette amplification en employant un procédé d'autocollimation basé sur la remarque suivante.

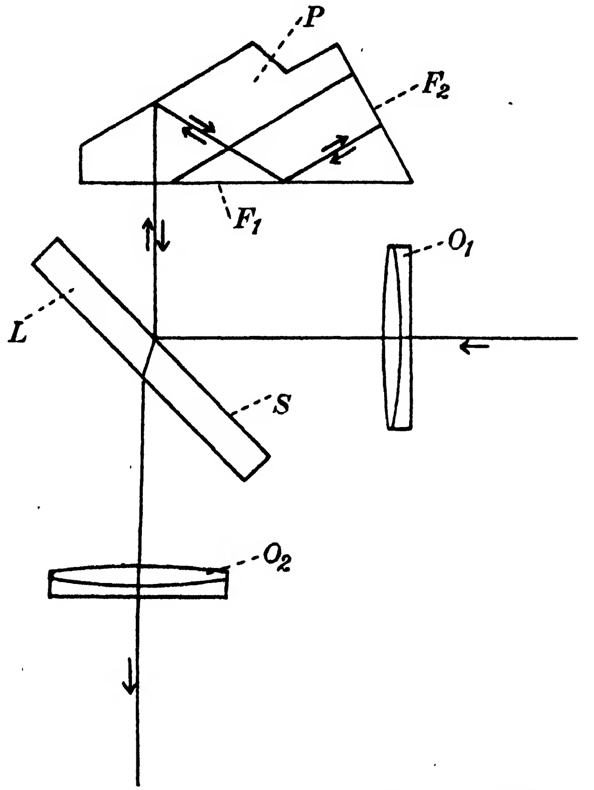
Un rayon lumineux perpendiculaire à la face d'entrée du prisme devient aussi perpendiculaire à sa face de sortie (aux erreurs d'angle près). La portion de ce rayon qui est réfléchie en arrière sur la surface de sortie sort encore du prisme normalement à la face d'entrée, mais l'effet d'une erreur du toit est doublé par la double réflexion sur ses faces. Cette image est d'ailleurs très lumineuse si la surface de sortie est argentée, et comme on argente souvent le prisme pour la retouche ce résultat est facile à obtenir.

On peut constituer comme suit l'ensemble du dispositif.

La lunette d'observation est établie comme à l'ordinaire, disons horizontalement.

Immédiatement devant on dispose, verticalement et à 45° sur l'axe optique de la lunette, une lame à faces bien planes et dont l'une de ces faces est semi-argentée. La lumière émanant d'une fente fine horizontale placée au foyer d'un collimateur est réfléchie par la lame non pas dans la lunette d'observation mais vers l'avant. Elle tombe alors sur la face d'entrée du prisme, le traverse deux fois et revient vers la lunette d'observation à travers la lame semi-argentée.

Pour finir, attirons l'attention sur la variété des services que peut rendre une lame à la fois réfléchissante et transparente employée comme ci-dessus, et sur la simplicité de son emploi.



O_1 Objectif du collimateur
O_2 Objectif de la lunette
L Lame semi-transparente
S Surface semi-transparente
P Prisme à étudier
F_1 Surface d'entrée
F_2 Surface de sortie, réfléchissante

REVIEWS

The National Physical Laboratory. Report for 1926. H.M. Stationery Office. Pp. 260. Price 7*s.* 6*d.*

(*Continued from p.* 400)

ELECTRICITY DEPARTMENT

In the measurement of *power loss in liquid dielectrics* a test condenser was used whose capacity in air did not change by more than 1 $\mu\mu$F when the condenser was taken down and reassembled. The quartz insulation was of very small volume and was kept well away from the field between the condenser plates. The dielectric constant of benzene has been examined with this condenser and the results are consistent to 1 part in 10,000.

A vertical force magnetometer has been made comprising a Helmholtz coil system with its axis vertical. At the centre a small light coil is suspended and acts as a vibration galvanometer in the earth's vertical field when supplied with alternating current at its resonant frequency: with 50 milli-amperes through the coil an amplitude of vibration of 180° can be obtained. The function of the Helmholtz system is to indicate the moment when the earth's field is neutralized by the reduction of the vibration to zero.

Variable air condensers of range 10–60 $\mu\mu F$ have been made designed for low minimum, permanence of calibration, and perfection of insulation. *Frequency standards* have been produced by actuating a 50~tuning-fork of low decrement by the usual interrupter, and giving it an additional impulse once per second by an electromagnet worked by a standard clock. The tuning-fork itself controls a multivibrator system, and finally it is possible to produce a frequency of a million per second, built up from the clock second. *Quartz resonators* have been thoroughly examined and their electrical identity with an equivalent network confirmed; the temperature coefficients of frequency for thin bars may be only a few parts in 10^6, while disks and plates vibrating transversely have coefficients amounting to 40 parts in 10^6.

The design of *equipment for measuring high voltages* is described. One of the chief difficulties in making measurements is the disturbance produced by corona discharge: the presence of this discharge is largely dependent on the curvature of the object subjected to the high voltage; accordingly an experimental determination has been made of the *distribution of electric stress in the space between two conductors*. The high voltage effects are imitated by immersing the system in a liquid of high resistance and using moderate alternating voltages. The equipotential surfaces are mapped out by a moving metallic point immersed in the fluid, and so the potential gradients close to the surfaces of the conductors can be studied and it becomes possible to design apparatus suitable for any given voltage.

Resistors for high voltages. Owing to the increased importance of capacity losses at high voltages a resistance carrying alternating current may possess a large capacity reactance owing to the presence of neighbouring conductors. The difficulty is partly overcome by dividing the resistor into separate sections and shielding these by metallic containers. These shields are connected to suitable points on a second resistor in parallel with the first, which keeps each shield at the same voltage as the part of the main resistor which it encloses: the method is not perfect, since the capacity currents in the secondary resistor upset the voltage distribution in the shields. Perfect compensation is secured by shielding the secondary resistor, and connecting the shields to suitable points on the transformer winding which is the source of the high voltage: since the resistance of the transformer winding is small the capacity losses in it are negligible.

In testing watt-hour meters a *very steady voltage supply for weeks* at a time is required. This is obtained by using a type of unbalanced tungsten lamp bridge due to F. G. H. Lewis, by which automatic voltage regulation steady to $\pm$ 0·2 per cent. can be obtained from a commercial supply. The method depends on the fact that for a certain range of values the resistance of a tungsten lamp increases with the filament temperature in such a way that the rate of increase of resistance is proportional to the rate of increase of current. The tungsten lamps are placed in two opposite arms of the bridge, and carbon lamps occupy the two other arms. The positive current resistance characteristic of the tungsten lamp is assisted by the negative characteristic of the carbon lamps. The fluctuating voltage is applied to two opposite points of the bridge and the output is taken from the other two opposite points.

The possibilities of *nickel-iron alloys of high magnetic permeability* and low hysteresis at low flux densities as cores for current transformers are examined with a view to work with *very high currents*. At present non-inductive resistances are available which allow measurements up to 2000 amperes. Beyond this value the constructional difficulties become very serious, and the power loss involved in the provision of a reasonable voltage drop for electrostatic instruments is also a difficulty. It seems, however, that the dynamometer system, using suitable current transformers, may provide a solution, since no special constructional difficulties should be involved in transformers for currents up to 10,000 amperes.

In wireless work the *propagation of waves* has been studied with reference to polarization phenomena. It was discovered that the marked change of bearing of a distant station observed at sunset could be explained by the reflection of a wave at an ionized upper layer of the atmosphere under the earth's magnetic field, with the result that the down-coming wave may be treated as still plane-polarized, with but its plane of polarization rotated about the direction of propagation.

A direction-finder free from night errors, invented by Adcock, which employs the equivalent of a pair of spaced vertical aerials arranged to rotate about a central vertical axis, has been tested. All the horizontal members of the system are compensated so that no E.M.F. is induced in the system by the horizontal electric fields which cause the errors in apparent bearing on the ordinary direction-finder. Excellent results were obtained. R. T. B.

(To be continued)

Navigational Wireless. By S. H. Long, D.Sc., M.I.E.E. Pp. xi + 164, with 162 illustrations. (London: Chapman & Hall, Ltd., 1927.) Price 12*s*. 6*d*. net.

The wireless direction-finder is rapidly becoming an indispensable instrument in both aerial and marine navigation. Recognizing this fact, the author of the present book has attempted to provide mutual instruction to the navigating officer and to the wireless operator, who are both concerned with this application of wireless communication.

The book opens with two elementary chapters giving briefly the principles of electrical circuits, including the use of the valve in wireless reception and the methods of screening electric and magnetic fields, the application of which is so vital in the construction of direction-finders. The next two chapters deal with the principles and methods of direction-finding. While most of the matter contained therein is well treated, it is apparent that some false conceptions on the subject have given rise to misleading statements in explaining the "vertical" or antenna-effect of a frame-coil, and also in describing the Robinson system of direction-finding. Throughout the book particular attention is given to the Siemens single-frame system of direction-finding, and chapter 5 gives detailed instructions for the installation of this system on board a ship. The following chapter deals with the calibration of the direction-finder, and the evaluation of the quadrantal error as a result of the effect of the ship's metal-work in distorting the field of the incoming waves. The author deals with this subject very fully, and shows how the resulting errors may be eliminated or compensated for in order to obtain accurate D.F. bearings. We have not noticed, however, any reference to the effect of the ship's draught on the quadrantal error, a point which is understood to be important in many cases.

The navigational side of the subject is well treated in chapters 7, 8 and 9, which describe the various charts necessary in plotting off bearings at sea, and the mode of applying corrections to the charted bearings. Several practical cases are described, with illustrations of the application of direction-finding to the position-fixing of ships at sea.

In chapter 10 the phenomena of coastal refraction and night effect in direction-finding are dealt with, but many statements therein tend to show that the author is unaware of much of the research on this subject which has been carried out in this country during the last few years. It is well known that, under conditions which are usually applicable in marine navigation, where the range of transmission is less than 80 miles and all oversea, wireless bearings are fairly free from night errors; but it is well for those responsible for navigation at sea to realize that, at all distances from 80 to well over 1500 miles, wireless bearings are subject at times to very serious night errors which may eclipse any other error associated with the system. Having realized the existence of the error, the navigator will treat such long-range bearings with suspicion, and may be instructed in the method of taking mean bearings to diminish the error of individual readings.

The book concludes with a short chapter on the application of sound-signalling devices to ships, and with some appendices giving notes, graphs and formulae, which may be of use in connexion with direction-finding. Throughout the book only one misprint has been observed, and a large number of good diagrams and photographs accompany the clearly printed text.

R. L. S. R.

X-Rays and Electrons. By A. H. Compton. Pp. xv + 403. (London: Macmillan & Co., Ltd., 1927.) Price 25*s*. net.

Professor Compton's book, outlining recent progress in X-ray theory and its bearing on the structure of matter and radiation, will be welcomed by all who are interested in the fundamental problems of physics. The treatment is mainly mathematical, the greater attention being paid to those aspects of the theory which are most closely allied with the author's own researches. Descriptions of experimental researches are usually brief, and the reader is recommended to refer to such works as Bragg's *X-rays and Crystal Structure* and Siegbahn's *Spectroscopy of X-rays* for experimental detail.

At the present time the controversy between the classical wave theory and the modern quantum theory still remains unsettled. It is inevitable therefore that any up-to-date book on X-rays must resolve itself into a statement of the rival theories. The present volume, apart from an introductory chapter, is divided into these two sections: (1) X-rays and Electrodynamics, and (2) X-rays and Quantum Theory.

The first section, after dealing with the general electromagnetic theory of X-rays, applies this theory in subsequent chapters to the problems of scattering, reflection from crystals, specular reflection, refraction, diffraction and absorption. The chapters dealing with the optical refraction and total reflection of X-rays are of particular interest, indicating recent developments in the determination of the refractive index (slightly less than unity) for waves of very high frequency. The diffraction of X-rays by a narrow slit and by means of a ruled grating also serves to illustrate the close resemblance of X-rays and ordinary light—an excellent photograph of an X-ray spectrum produced by means of the ruled grating is very striking in this respect. The author's statement that "the study of X-rays is a branch of optics" appears to be amply confirmed in these chapters on the classical wave theory.

The second section of the book, dealing with X-rays on the quantum theory, indicates clearly where the classical wave theory breaks down and the quantum theory succeeds. Thus the electromagnetic theory fails to account for the radiation of light and the origin of X-rays. The inability of the classical theory to explain the scattering phenomena of penetrating X-rays, and the success of Professor Compton's quantum theory of scattering, indicate a noteworthy advance made during recent years. The quantum explanation, which involves change of wave-length with angle of scattering but is independent of the scattering material, has been brilliantly confirmed experimentally.

In spite of this and other similar advances, however, the issue is not clear and we are still left in the open ground between the rival theories.

The book is well written by an authority on the subject, and it requires no other recommendation to those interested in the progress of atomic physics. A few minor defects, mainly printers' errors, might be mentioned, but these will no doubt be overlooked by the interested reader in view of the general excellence of the book.

A. B. W.

CATALOGUES

THE CAMBRIDGE INSTRUMENT COMPANY have issued a Catalogue, No. 907S, in the Spanish language, describing their works and offices, and their various instruments for use in power stations, such as CO_2 recorders, distance thermometers and pyrometers, recorders and controlling devices, calorimeters and electrical testing sets. An interesting feature of the catalogue is the pair of schematic diagrams on the first two pages, showing the measuring arrangements required in the boiler house and machine room respectively, and where the various instruments described should be installed. At the end of the list illustrations of a variety of the well-known instruments constructed by the company are inserted.

We have received a new list, Serial No. 2, giving particulars and prices of the "Becol" ebonite manufacturers of the British Ebonite Co., Ltd., Nightingale Road, Hanwell, W. 7. Useful data are given of the standard rods, tubes and sheets made, and of particular interest is the extruded work, in various sections, and made in lengths up to 36 inches. Thus, circular knobs for wireless work can be cut from the fluted rods of sections 37 to 42, and small insulators and coil mounts may be made from pieces cut from section 19, which contains two $\frac{1}{4}$-inch holes at $\frac{9}{16}$ inch apart. The rectangular sections 18 and 21 serve as formers for small rheostat windings.

Messrs W. and G. Foyle, Ltd., 119 to 125 Charing Cross Road, W.C. 2, send their latest catalogue No. 7 of new and second-hand books on technical subjects and applied science. Readers contemplating the purchase of books in any branch of applied science would do well to consult this list. A large number of the standard works are listed, in many cases at considerably less than the published prices.

SCIENTIFIC INSTRUMENTS AT THE BRITISH INDUSTRIES FAIR

We have received from the Department of Overseas Trade, 35 Old Queen Street, S.W. 1, particulars of the arrangements for the British Industries Fair, 1928. As in former years, the fair is to be held simultaneously in London and Birmingham, the London section at the White City, Shepherd's Bush, from February 20th to March 2nd.

This Government organized annual trade fair is one of the most important of the post-war activities of the Government in relation to the industry of the country. Its growing importance is evidence alike of its thorough organization and of the increasing interest with which it is regarded by manufacturers. Its purpose is to introduce British manufactures to purchasers at home and abroad, and in view of the post-war conditions in the optical and related industries, the facilities which the fair offers, particularly to firms desirous of establishing an overseas connexion, should make it of special interest to manufacturers of optical and general scientific instruments.

A special effort is being made this year to extend the Scientific, Photographic and Surgical Instruments Section in London, and to make it representative of the industry. The section will have a hall of about 5500 square feet to itself, and of this nearly two-thirds has already been allotted, many well-known instruments firms having taken space.

The Government is spending £25,000 in advertising the fair. An early overseas edition of the catalogue is published, giving the exhibiting firms and short particulars of the exhibits, and this year will be distributed overseas at the beginning of January, some seven weeks before the opening day. In previous years this early edition has proved to be of great value. The catalogue itself, a classified book of reference to the fair, is printed in nine languages and is distributed very widely at home and abroad.

JOURNAL OF SCIENTIFIC INSTRUMENTS. BACK NUMBERS

Two shillings per part will be paid for clean, undamaged copies of parts 1, 2, 4, 11 and 12 of Volume 1 of the *Journal*. These should be sent to the Secretary, Institute of Physics, 1 Lowther Gardens, Exhibition Road, London, S.W. 7.

TABULAR INFORMATION ON SCIENTIFIC INSTRUMENTS

A few sets of the separate tables remain, and may be obtained on application to the Secretary, Institute of Physics, 1 Lowther Gardens, Exhibition Road, London, S.W. 7, at a cost of 5*s*. per set. The sets contain eighteen tables, and are complete except for Table II: British Photographic Lenses, which is out of print.

JOURNAL OF SCIENTIFIC INSTRUMENTS

VOL. IV NOVEMBER, 1927 No. 14

AN AUTOMATIC CLOUD CHAMBER FOR THE RAPID PRODUCTION OF ALPHA RAY PHOTOGRAPHS.

By P. M. S. BLACKETT, M.A., Fellow of King's College, Cambridge.

[*MS. received, 18th July, 1927.*]

ABSTRACT. An automatic cloud chamber apparatus is described for taking large numbers of alpha ray photographs as rapidly as possible.

The conditions for producing good tracks, and the cycle of operations required to realize these conditions, are discussed. An outline of the general design of the apparatus in its final form is given, followed by a detailed description of the chamber itself and of the source and alpha ray shutter.

1. INTRODUCTION

FROM a pair of stereoscopic photographs, taken by the Wilson method, of a collision of an alpha particle with a nucleus, certain information can be obtained which can be obtained in no other way. But the collisions of greatest interest are always of great rarity. Therefore to obtain even a few tracks of value it is necessary to photograph a great many. To do this most conveniently there should be as many tracks as possible on each photograph and the photographs should be taken as rapidly as possible. Two photographs from different directions must always be taken in order that the actual form of any collision may be determined. There must also be a reasonably high chance that any given track will appear clear of its neighbours in both images. Photographic convenience necessitates the use of standard cinematographic film (2·5 cm. broad between perforations). This sets certain limits on the choice of the size of the expansion chamber, magnification of the camera etc. These latter considerations, in fact all those concerning the attainment of the maximum number of tracks in a photograph, will be discussed in another paper. This paper will be chiefly concerned with the problem of taking alpha ray photographs as rapidly as possible.

The first attempt to make a rapid and automatic Wilson apparatus was made in the Cavendish Laboratory by Shimizu* in 1921. This type of apparatus has since been used by Harkins and Shadduck† and recently by Holoubek‡. The principle of the method was to substitute for the isolated sudden expansion of Wilson's apparatus a continuous series of expansions and compressions produced by a piston moving with simple harmonic motion. Though considerable success was obtained with this apparatus, it suffered from certain serious disadvantages, the nature of which will be discussed later. In 1922 Shimizu's work was continued by the author, and the apparatus modified§. The continuously moving

* Shimizu. *Proc. Roy. Soc.* **99** (1921) 425.
† Harkins and Shadduck. *Proc. Nat. Acad. Amer.* **12** (1926) 707.
‡ Holoubek. *Zeit. f. Phys.* **42** (1927) 704.
§ Blackett. *Proc. Roy. Soc.* **102** (1922) 294; **103** (1923) 62.

piston was abandoned in favour of one producing a series of isolated and sudden expansions. In effect the Wilson technique was re-adopted. The apparatus reached its final form in 1924 and was then used to photograph the ejection of protons from nitrogen nuclei*. It is not claimed that this apparatus is entirely satisfactory either in design, construction or reliability. It has however proved effective. With it nearly 50,000 photographs have been taken, giving in all photographs of about 800,000 alpha ray tracks.

Although it is easy to take alpha ray tracks it is not so easy to take very good ones. The original Wilson technique remains perhaps unsurpassed for this purpose. Modifications of this method have been developed by Meitner† and by Auger‡ and have also given very beautiful results. To take a very large number of very good photographs a reliable and automatic apparatus is essential. It is most important that it should be possible to make all the requisite adjustments while the apparatus is running continuously.

2. The Conditions for Good Tracks

To produce good tracks the following conditions must be satisfied:

(1) The gas in the chamber before the expansion must be saturated with water vapour and be at a uniform temperature. A considerable time must therefore be allowed between expansions for equilibrium to be attained.

(2) No condensation ions must be present at an expansion other than those produced at the correct moment during the expansion by the rays from the radioactive source. Now when the piston rises after an expansion the drops do not completely re-evaporate, but leave behind nuclei which are *large* in the sense that a very *small* expansion is able to condense water upon them. If they are not removed before the next expansion the new tracks will be marred by a background of fog or even by the ghosts of the old tracks. In spite of their very small mobilities most of these nuclei can be removed by a strong electric field. But some are uncharged and must be removed by again condensing water upon them and letting them settle to the bottom of the chamber. Thus between two expansions to give tracks an expansion must be made, too small to condense water of ions but large enough to condense water on these *large* nuclei. The expansion must be maintained till the drops formed have sunk to the bottom of the chamber. It is not always possible to remove all these nuclei by one such halfway expansion, since the drops may re-evaporate before reaching the floor of the chamber. To clear the background completely two or more halfway expansions may be required. One only has been used in the apparatus to be described. This method of intermediate small expansions is due to C. T. R. Wilson.

(3) As the track formation depends primarily on the degree of supersaturation, this must be susceptible to fine and easy control. This is most easily obtained by using an expansion rapid enough to be appreciably adiabatic.

(4) The alpha rays must be prevented by a shutter from entering the chamber till sufficient supersaturation is attained. It is advisable but not absolutely necessary to close the alpha ray shutter again before the supersaturation has been lowered by conduction from the walls. Tracks formed by rays passing too early, that is before the supersaturation is sufficient, are broad and dense and so seriously interfere with the correct track formation. Tracks formed by rays passing too late, that is, when the supersaturation has again ceased to be sufficient, are thin and often incomplete; though themselves imperfect, they do not seriously interfere with the perfect tracks. If angle measurements of the highest precision are to be made on the tracks the rays must not enter till the expansion is quite complete.

* Blackett. *Proc. Roy. Soc.* **107** (1925) 349.
† Meitner and Freitag. *Zeit. f. Phys.* **37** (1926) 481.
‡ Auger. *Thesis*. Paris. 1926.

otherwise the tracks will be deformed by the remaining expansion. In order that the shutter should be easily controlled it must be worked by a mechanism external to the chamber. If it is desired that the fastest alpha rays should be used, the source of alpha rays must be inside the chamber, so as to avoid the loss of range by passing through a window.

With the Shimizu apparatus it is impossible to satisfy the first three conditions. To do this a more complicated cycle of operations is required.

3. The Cycle

The movement of the piston during the cycle adopted is shown by the black line in Fig. 1. The length of the cycle is about 13 seconds. This was the shortest cycle that was found to give really good tracks with this small chamber of 6 cm. diameter. For a larger chamber possibly a longer cycle would be required.

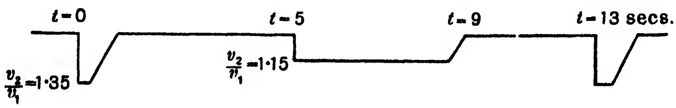


Fig. 1

At $t = 0$ the piston drops for a full expansion, for which, for a diatomic gas, $v/v_0 = 1{\cdot}35$ approximately*, and a photograph is taken. Immediately afterwards the piston rises to its initial position, where it remains till the fifth second, allowing time for the dispersal of the majority of the old nuclei. The piston then falls halfway ($v/v_0 = 1{\cdot}15$), condensing water on the nuclei remaining. These have mostly reached the floor of the chamber by the ninth second, when the piston rises again, to await the next full expansion at the thirteenth second, allowing time for approximate temperature equilibrium to be attained. An electric field of about 100 volts per cm. is maintained throughout to assist the removal of the nuclei, except actually during the expansion, when it is reduced to about 6 volts per cm. to avoid spreading out the ions during the track formation. This cycle has proved very successful, but no special merit is claimed for the exact figures given.

4. The Apparatus

The main features of the apparatus, which is a development of that described in a former paper, are shown diagrammatically in Fig. 2. The piston of the expansion chamber C is actuated by a rod attached at B to a bar J. This bar is pivoted at A and rests on a hardened steel catch E. A strong spring D moves the bar suddenly downwards when the catch E is released. The motion of the bar is arrested by an adjustable stop F and is prevented from bouncing by a special catch.

The cycle of operations is produced by the rotation in the cycle period of 13 seconds of a wheel G. A cam on this wheel trips the catch E at the beginning of the expansion; a second cam frees the anti-bounce catch on F, allowing a roller H to lift the bar again on to the catch E. A third cam serves to insert a metal plate between the bar and the stop F, so that when a fourth cam trips E again the bar only falls halfway. A second roller H' lifts the bar again ready for the next expansion.

The expansion chamber itself is a development of that used by Kapitza†. It consists essentially of a glass cylinder M (Fig. 3), closed at the top by a plate glass disc N, and cemented at the bottom to a brass cylinder O, which is closed by a flexible corrugated

* The expansion ratio for good tracks varies slightly with the time of the cycle. The final adjustment must be done while the apparatus is running continuously.

† Kapitza. *Proc. Roy. Soc.* **106** (1924) 602.

metal diaphragm P. The lower part of the vessel is completely filled with water, by means of two tubes WW. Closely fitting the glass cylinder is an ebonite piston Q made to float on the water about three-quarters immersed, by means of an internal glass float and paraffin wax filling. The diaphragm is actuated by the rod R attached to the main bar

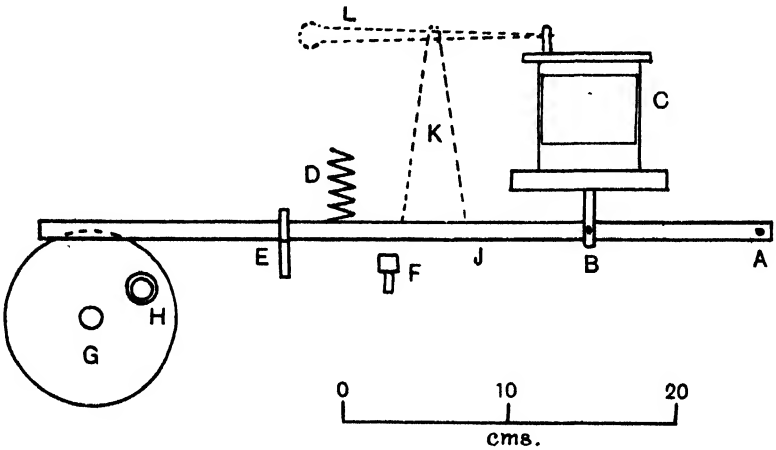


Fig. 2

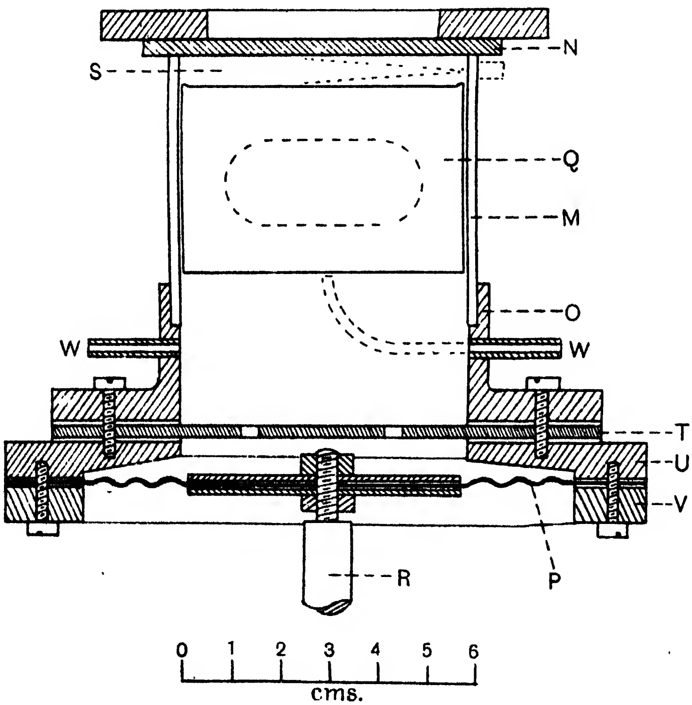


Fig. 3. The expansion chamber

at B, Fig. 2. When the expansion is made by tripping the catch E the sudden motion of the bar is communicated to the diaphragm and so to the piston, causing an expansion of the gas in the space S. The initial height of this space is about 6 mm., so that a movement of the piston of about 2 mm. is required for the expansion. It is found that the centre of the diaphragm must move about 1·8 mm., in order to give this motion to the piston. In order to prevent the piston, water and diaphragm from vibrating at the end

of the expansion, a metal baffle plate T is fitted between the piston and the diaphragm. In this plate are bored a number of holes of such a size that the whole vibrating system is critically damped by the viscous forces arising from the flow of the water through the holes*. The effect of this viscosity damping of the motion of the piston was studied by means of a mechanical oscillograph, which produced a trace of the motion of the piston on a falling photographic plate. It was found that the expansion was complete in about 1/100 of a second. Most of the work with this apparatus was done before the baffle plate had been fitted, and excellent tracks were obtained, in spite of the vibration of the piston at the end of the expansion. The track formation must have been limited to a very small period of time near the instant of maximum displacement. After the baffle plate had been fitted to damp out the vibrations the apparatus behaved more consistently and was easier to adjust. Also the number of tracks for a given strength of source was greater, owing to the longer time of effective supersaturation.

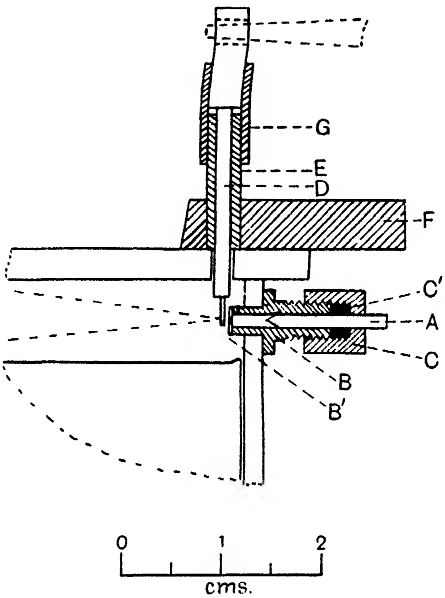


Fig. 4. Alpha ray source and shutter

The arrangement of alpha ray source and shutter is shown in Fig. 4. The thorium active deposit, used as the source, is deposited on the coned end of the platinum wire A. This wire fits into the brass cylinder B, the end of which is closed by a thin plate B', in which is cut a horizontal slit, 1·0 by 0·3 mm. A fan-shaped beam of rays about 20° wide is thus obtained, which is sufficiently flat to prevent any of the rays touching the top or bottom of the chamber. The source holder itself is cemented into a hole in the glass cylinder and is closed at its outer end by a brass cap C and rubber washer C'. This arrangement allows the source to be inserted or removed at will.

The slit is closed by the flat end of a brass rod D which projects through a hole in the top of the chamber. The rod slides in a tube E attached to the metal ring F cemented to the top of the chamber. A thin piece of rubber tubing G secured to both rod and tube serves to prevent a leak. At the correct moment during the expansion the rod is jerked upwards, uncovering the slit and allowing the alpha rays to enter the chamber. To do this two mechanisms have been used. The first, which is shown dotted in Fig. 2, consists of

* The joints between O, T, U, V, P and R are made tight by rubber washers.

a bracket K rigidly attached to the main bar. On the bracket is pivoted a lever L, one end of which is weighted and the other end of which projects through a hole in the top of the shutter rod. When the bar J drops the inertia of the weighted lever will keep the shutter closed till the bar hits the stop, when the shutter will be opened. Since the piston follows closely the motion of the bar, this results in the shutter opening very nearly at the end of the expansion.

This simple arrangement, which was used with success throughout the work on nitrogen, was later replaced by a more complicated mechanism, which allows the time of opening of the shutter to be controlled at will. In this the shutter rod is pressed up by a spring, but kept from opening by a catch. The catch is released by a system of levers set in motion by the main bar. One of the levers is fitted with an adjustable oil brake, so that the time of opening of the shutter can be easily and finely adjusted. This mechanism did not close the shutter again, but the tracks were not appreciably worse on this account. The strength of the source of thorium $B + C$ varied from 0·1 to 0·2 mg. γ ray activity. The numbers of tracks in each photograph varied, from 15 to 30, with the strength of the source and the adjustments of the chamber. As the least trace of radioactive material in the gas or on the walls of the chamber interferes seriously with the track formation, the platinum source, after exposure to the thorium emanation, was washed in alcohol and heated to a temperature of about 500° C., to remove traces of radium emanation arising from the parent radio-thorium source.

In the earlier work with this apparatus the system of illumination consisted of two arc lamps burning flame carbons. The arcs were run as low as possible, except actually during the expansion, when a switch operated by a cam on the main wheel short circuited a series resistance, giving a short flash of intense light of about one second duration. The camera was fitted with a Compur type shutter, released by a Bowden wire operated through a delay action mechanism by the fall of the main bar. The exposure was usually about 1/25 sec. In order to get sharp photographs it was found necessary to delay the opening of the shutter about 1/10 sec. in order to give time for the vibration of the whole apparatus due to the shock of the expansion to die down.

Though very good photographs were obtained by this method, still better were obtained when the arc lamps and camera shutter were replaced by a spark discharge through quartz mercury vapour lamps, of the type used by C. T. R. Wilson. Owing to the short duration of the flash the mechanical vibration of the apparatus can cause no blurring of the images. Another advantage lay in the avoidance of the necessity of relying on the mechanical efficiency of the camera shutter. (As a matter of fact the shutter originally used, an "Ilex" Compur type, only began to fail after about 15,000 photographs.)

The condensers had a capacity of 1/30 M.F., and were charged to a potential of about 35,000 volts by a Müller type coil and a large rectifier of the Kenotron type. The primary circuit of the coil was completed about 3 seconds before the expansion by a contact on the wheel, this time being sufficient for the condensers to become fully charged by the time of the expansion. Some difficulty was experienced owing to the breaking of the quartz lamps. Eventually tubes of about 3 mm. internal diameter were used, as they were found to give a longer life, for a given strength of flash, than the tubes of 1 mm. bore used by C. T. R. Wilson, which however give much more light for a given energy.

5. The Performance of the Apparatus

As the essential quality of such an apparatus is its reliability, some indication will be given of its actual performance in this respect. The lighting arrangements remain the least reliable factor. Perfect regularity in the illumination is required, and this has not yet been attained. The chamber itself has proved fairly reliable; as many as 5000 photographs

have been taken without its being stripped. The glass top of the chamber is used dry, that is, without a gelatine coat. This avoids the trouble due to the formation, after some days, of large drops of water on the gelatine; but introduces another, though lesser trouble, of a rather obscure nature. After some days of use the glass sometimes appears to acquire the property of inducing the deposition of moisture, even when itself above the temperature of the gas. Possibly a slow reaction takes place between the gas, the water vapour and the glass, producing some hygroscopic substance. This clouding of the glass is one of the most frequent causes of breakdown.

Many other breakdowns are due to the failure of parts of the somewhat complicated driving mechanism, due usually to the deficiencies of amateur workmanship.

As the cycle is 13 seconds, about 270 photographs are taken in an hour. The most ever taken in a day is 1270, which, at the rate of 20 tracks a photograph, gives about 25,000 tracks. The discussion of section 2 shows that an increase in the rate of photographing tracks is to be sought rather in the increase of the number of tracks in each photograph than in the number of photographs in an hour. The limit to the former number is set by the condition that there shall be a reasonable chance that any given track shall be clear of its neighbours. In the work of Meitner and Freitag, where it was not necessary to satisfy this condition, several thousand tracks were obtained on each photograph. The whole of the large chamber used by these authors was in sharp focus owing to the use of an ordinary stereoscopic camera mounted vertically above the chamber. When, however, it is necessary to deduce from the photographs the actual form of the forked tracks, it is essential to take two photographs from directions nearly at right angles. This introduces a difficulty due to the small depth of focus of a lens. In the camera used with the apparatus described in this paper the two focal planes were exactly at right angles to each other and made an angle of 45° with the plane of the chamber. Only a small region in the centre of the chamber could therefore be in focus, and the resulting necessity of limiting the beam of rays to this region limited the average number of tracks in each expansion to about twenty. A new camera, in which this difficulty is avoided, is now being built.

The carrying out of this work has been made possible by grants of money from the Research Fund of King's College, from the Government Grant Committee of the Royal Society and from the Caird Fund of the British Association for the Advancement of Science. I wish to thank the General Electric Company Ltd., of London, for the gift of the valve rectifier used with the spark illumination.

The greater part of the work of the last year, the adoption of the spark lighting, the improvement of many parts of the apparatus, and the subsequent study, as yet incomplete, of the scattering of alpha particles in hydrogen, involving the photographing of 200,000 tracks, has been carried out with the help of Mr E. P. Hudson, B.A., of King's College. I wish to thank him for this invaluable assistance.

To Sir Ernest Rutherford, P.R.S., who first appreciated the importance, for the study of nuclear collisions, of the rapid production of alpha ray photographs, to whom the initiation of this work is due, and without whose constant encouragement it would not have been carried out, I wish to express my gratitude.

THE CAVENDISH LABORATORY
CAMBRIDGE.
May 1927.

ELECTROMAGNETIC FORCES ON CURRENT-CARRYING CONDUCTORS. By W. F. DUNTON

[*MS. received, 8th June*, 1927.]

ABSTRACT. The author points out that serious errors are frequently made in the design of electromagnetic devices by using the formula for the field of an infinite straight conductor when the conductor is of finite length. Examples of such errors are given, and correct formulae are worked out.

I. Introduction

STARTING from two well-known fundamental laws of electromagnetism, the present article deduces formulae for calculating the forces with which two given straight conductors react upon each other when traversed by given currents, these conductors being either parallel or inclined at some angle between 0° and 180°.

At first it may be thought that formulae sufficient for these everyday cases are to be found in any of the well-known handbooks for electrical engineers. But this is not so. Neither of the general formulae that are here stated and proved appears to have been stated before; and, in the writer's own experience, the usual formulae for certain special cases have led to serious mistakes in the design of electrical apparatus. It will here be shown that these special formulae hold good only with certain limitations, which was doubtless realized when the formulae were first given, but is now frequently overlooked.

The article concludes by showing that the law of electromagnetic induction ought to be stated with reference to the rate of change in the flux linkage, and not with reference to the rate at which conductors are cutting across flux. The general idea appears to be that these two points of view must always lead to the same conclusion; but a case is here given in which they indisputably lead to different conclusions, with reference to laboratory tests showing which conclusion is correct.

In order to make the mathematical arguments as simple as possible, the customary C.G.S. system of electromagnetic units will be used throughout this article. (This is the system in which the unit of current is 10 amperes, the unit of electromotive force is 10^{-8} of a volt, and the unit of magnetic flux is the maxwell.) The symbol *lgn* is here adopted as the most satisfactory of the various abbreviations for "natural logarithm"—that is, for $\log_e$.

The length, cross-section and arrangement of the conductors are supposed to be such as to justify the usual assumption as to the currents being concentrated on the centre lines, an assumption that greatly simplifies the mathematics.

II. Two Straight and Parallel Conductors

By a fundamental law of electromagnetism it may be reckoned that the flux density at the point y in Fig. 1, due to the current I in dx at x, is

$$\frac{I\,dx \sin v}{z^2} \qquad \text{......(1)};$$

that is to say, the actual flux density at the point y, due to the current I in the conductor gh, can be found by integrating (1). The direction of the flux will be perpendicular to the plane that contains the parallel conductors ab and gh, and the tendency will be for the conductors to approach each other in that plane if the currents I and J have the same direction (as indicated in the diagram), and to recede from each other in that plane if the currents are in opposite directions.

In view of what is to follow, the most convenient way of integrating (1) will be by first expressing z^2 and $\sin v$ as functions of x. Evidently

$$z^2 = s^2 + (x - y)^2$$

and

$$\sin v = s/z,$$

so that (1) is equivalent to

$$\frac{Is\,dx}{\{s^2 + (x - y)^2\}^{\frac{3}{2}}} \qquad \text{......(2).}$$

This is the differential of

$$\frac{I\,(x - y)}{s\sqrt{s^2 + (x - y)^2}}.$$

The flux density at y due to the current in the whole of gh is therefore

$$\frac{I}{s}\left\{\frac{h - y}{\sqrt{s^2 + (h - y)^2}} + \frac{y - g}{\sqrt{s^2 + (y - g)^2}}\right\} \qquad \text{......(3).}$$

If s^2 is negligibly small in comparison with $(h - y)^2$ and $(y - g)^2$, (3) becomes $2I/s$. This, then, is the flux density produced at a point outside and near the middle of a long and straight conductor, by the current I in that conductor; or, rather, this is the limit that the flux density approaches as the length of the conductor is indefinitely increased, s being the perpendicular distance of the point in question from the axis of the conductor.

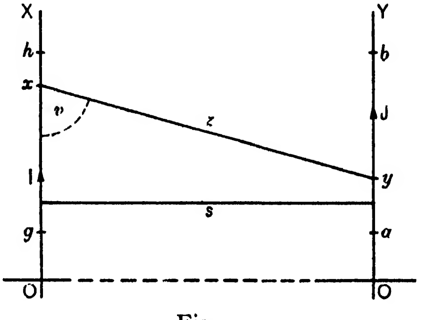


Fig. 1

But if, while s^2 is negligibly small in comparison with $(h - y)^2$, g is equal to y, then (6) becomes I/s. This, then, is the flux density produced at a point outside and near the end of a long and straight conductor, by the current I in that conductor; or, rather, this is the limit that the flux density approaches as the length of the conductor is indefinitely increased.

When a current-carrying conductor lies in a magnetic field whose density is B and whose direction makes an angle A with the direction of the current, the magnitude of the force that is thereby exerted on the conductor is $JBn \sin A$, where J is the current and n is the length of the conductor. In the case we are now considering, A is a right angle, and the magnitude of the force is therefore simply JBn. The expression for the force on dy at y (see Fig. 1), due to the current in the whole of gh, is accordingly obtained on multiplying (3) by $J\,dy$. It will be found that the expression thus obtained is the differential of

$$\frac{IJ}{s}\{\sqrt{s^2 + (y - g)^2} - \sqrt{s^2 + (h - y)^2}\},$$

so that the force on the whole of ab, due to the current J in this conductor and the current I in the whole of gh, is

$$\frac{IJ}{s}\{\sqrt{s^2 + (b - g)^2} - \sqrt{s^2 + (h - b)^2} - \sqrt{s^2 + (a - g)^2} + \sqrt{s^2 + (h - a)^2}\}.$$

This expression may be put in a form that is much more convenient for calculations with the help of a slide rule, namely,

$$IJ\left\{\sqrt{\left(\frac{b - g}{s}\right)^2 + 1} - \sqrt{\left(\frac{h - b}{s}\right)^2 + 1} - \sqrt{\left(\frac{a - g}{s}\right)^2 + 1} + \sqrt{\left(\frac{h - a}{s}\right)^2 + 1}\right\}$$

......(4).

If we put $b = h$ and $a = g = 0$ in (4), we get the following special formula for the force between two parallel conductors, each of length h, situated directly opposite each other at an axial distance s, and carrying currents of I and J respectively:

$$F = 2IJ\left\{\sqrt{\left(\frac{h}{s}\right)^2 + 1} - 1\right\} \qquad \text{......(5).}$$

It is to be hoped that this formula will soon replace the one that is still frequently used by designers of electrical apparatus, namely,

$$F' = 2IJ\frac{h}{s} \qquad \text{......(6).}$$

A little consideration will show that (5) and (6) are practically equivalent when s/h is a very small fraction; but when h is not greater than $\frac{1}{2}s$ (as in several cases to which the writer has seen (6) applied) the square root in (5) is evidently less than $1\frac{1}{8}$, so that F is less than $\frac{1}{4}F'$.

Another point in connexion with which a warning may be desirable, is the great difference between the flux density that is produced near the middle and near the end of a long and straight conductor, by the current that this conductor carries. It has here been shown that the flux density at a point near the middle is practically twice as great as at a point near either end, supposing that the perpendicular distance of the point from the conductor is a very small fraction of the length of the conductor. Yet the above-mentioned $2I/s$, which is not even approximately correct for a point near either end, is frequently used with the idea that it holds good all along the conductor. Sometimes, too, mistakes are made through a failure to understand that the s in the above expression is assumed to be a small fraction of the length of the conductor. The reason for this assumption will be clear from the manner in which formula (3) was proved, in conjunction with the paragraph that follows that formula.

Finally, it may be mentioned that $2I/s^2$ is sometimes given instead of $2I/s$, apparently through a confusion with (1), where the z^2 is correct.

III. Two Straight Conductors inclined at a Given Angle

In Fig. 2, ab and gh are two straight conductors, and u is the angle by which the directions of the currents differ: that is to say, u is the angle through which the line ab would have to be turned in order to make the current I have the same direction as the current J.

By a fundamental law of electromagnetism, it may be reckoned that the flux density at x due to the current J in dy at y is

$$\frac{J\,dy \sin v}{z^2} \qquad \text{......(7);}$$

that is to say, the flux density at x due to the current J in the conductor gh can be found by integrating (7).

By a well-known proposition in trigonometry,

$$\frac{\sin v}{\sin(180° - u)} = \frac{x}{z},$$

which enables us to convert (8) into

$$\frac{J\,dy\,x \sin(180° - u)}{z^3}.$$

By another well-known proposition in trigonometry,

$$z^2 = x^2 + y^2 + 2xy \cos u.$$

Remembering that $\sin(180° - u) = \sin u$, and using c as an abbreviation for $\cos u$, we may now write (7) in the form of

$$\frac{J\,dy\,x\sin u}{(x^2+2cxy+y^2)^{\frac{3}{2}}} \qquad \text{......(8).}$$

As the direction of the flux is at right angles to the direction of the current I in ab, the consequent force on dx at x is simply (8) multiplied by $I\,dx$; and if the expression thus obtained is integrated with respect to y, from $y = g$ to $y = h$, this will give the force on dx at x due to the current I in this element and the current J in the whole of gh. The direct integration is here rather difficult, and the result is sometimes given incorrectly. However, it is comparatively easy to prove, by differentiation, that the correct result is

$$df = IJx\sin u\,dx\left[\frac{y+cx}{(x^2-c^2x^2)\sqrt{x^2+2cxy+y^2}}\right]_g^h.$$

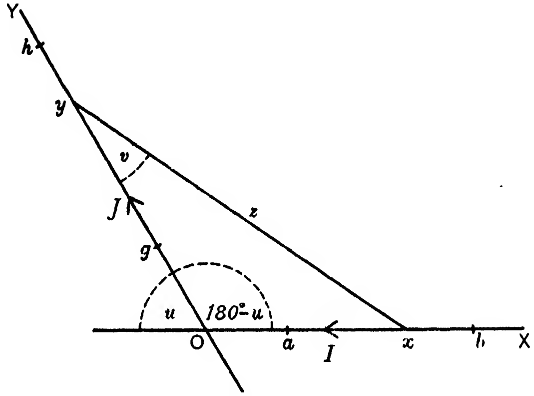


Fig. 2

Noticing that $x^2(1-c^2) = x^2\sin^2 u$, and using $H(x)$ and $G(x)$ to indicate the functions $\sqrt{x^2+2chx+h^2}$ and $\sqrt{x^2+2cgx+g^2}$ respectively, we may express the final result of the above integration as

$$df = \frac{IJ}{\sin u}\left\{\frac{(h+cx)\,dx}{xH(x)} - \frac{(g+cx)\,dx}{x\,G(x)}\right\}.$$

To find the force exerted on the whole of ab by the interaction of the current I in this conductor and the current J in the whole of gh, we must now integrate df with respect to x. Here again the direct integration is not easy; but it is comparatively easy to prove that

$$\frac{h}{xH(x)} \text{ is the differential coefficient of } lgn\,\frac{x}{H(x)+cx+h}$$

and $$\frac{c}{H(x)} \text{ is the differential coefficient of } c\,lgn\,\{H(x)+x+ch\}.$$

The required indefinite integral will therefore consist of the sum of this lgn and $c\,lgn$, minus the sum of two similar expressions with G and g in place of H and h. We accordingly have, as the result of integrating df from $x = a$ to $x = b$,

$$f = \frac{IJ}{\sin u}\left\{\begin{array}{l} lgn\left(\dfrac{H(a)+ca+h}{H(b)+cb+h}\times\dfrac{G(b)+cb+g}{G(a)+ca+g}\right) \\ -\,c\,lgn\left(\dfrac{H(a)+a+ch}{H(b)+b+ch}\times\dfrac{G(b)+b+cg}{G(a)+a+cg}\right)\end{array}\right\} \qquad \text{......(9).}$$

In the special case in which the conductors meet at right angles and carry the same current, as in Fig. 3 (which represents the horizontal crossbar and the vertical leads of an ordinary circuit breaker), we have $J = I$, $\sin u = 1$, $c = 0$, $g = 0$ and $a = r$, where r is the radius of the vertical conductor. Formula (9) thus becomes

$$f' = I^2 \, lgn \left(\frac{b}{r} \times \frac{\sqrt{r^2 + h^2} + h}{\sqrt{b^2 + h^2} + h}\right)$$

or

$$f' = I^2 \, lgn \left(\frac{b}{r} \times \frac{\sqrt{(r^2/h^2) + 1} + 1}{\sqrt{(b^2/h^2) + 1} + 1}\right) \qquad \ldots\ldots(9\,a).$$

But, in an ordinary circuit breaker, r^2/h^2 will be a negligibly small fraction. In this case, then, we have the following formula for the total force on the crossbar (of length b) due to the interaction of the current I in this and in the two vertical conductors (each of length h and of radius r):

$$F = 2I^2 \, lgn \left(\frac{b}{r} \times \frac{2}{\sqrt{(b/h)^2 + 1} + 1}\right) \qquad \ldots\ldots(9\,b).$$

As this formula may be regarded as containing only four variables, F, I, b/r and b/h, it admits of being put in the shape of a fairly simple nomogram that will enable any one of these variables to be found when the other three are given. Such a nomogram was got out by the present writer some time ago, and the results obtained from this were found to be in practically perfect agreement with those subsequently given by a series of laboratory tests.

The tests here referred to were undertaken owing to the great discrepancy between the results obtained from the nomogram and those obtained from the formula given by Ludwig Kopec in *Elektrotechnik und Maschinenbau* dated 30th August 1925. Assuming the correctness of Kopec's formula,

$$F'' = I^2 \left\{\left(lgn \frac{b}{r}\right) + 0{\cdot}25\right\} \qquad \ldots\ldots(10),$$

it appeared that the results obtained from my nomogram must be much too great. But the tests clearly proved that there must be something wrong in Kopec's argument; and it will now be well to show exactly where the fallacy lies, as others may have been misled in the same way, in this and in other matters.

Kopec's method of dealing with the problem is as follows:

> Imagine the crossbar moving vertically downwards under the action of the unknown force F, so that the work done when the bar has moved through the very small distance dy is $F\,dy$.
>
> Calculate the magnetic flux M that would be cut across by the bar in making the above-mentioned movement.
>
> Put $F\,dy = \frac{1}{2}IM$, on the principle that the mechanical work is equal to the increase in the stored magnetic energy, which increase is $\frac{1}{2}I^2 dL = \frac{1}{2}IM$, where dL is the increase in the self-inductance of the loop (Fig. 3) due to the stretching of the loop by the movement of the bar.

As the following considerations will show, the mistake lies in the last equation, though this equation is quite in accordance with what appears to be the usual teaching.

Referring to Fig. 3 and equation (6), it will be seen that the force with which the current in Oh would act upon a conductor that coincided with xh' and carried a current J, is $2IJh/x$, supposing that x/h is a sufficiently small fraction. This means that $2I/x$ is the average flux density, as will be evident from the manner in which equation (6) was arrived at. It follows that the flux through the vertical strip of length h and breadth dx is $2Ih\,dx/x$, and that if h is increased by the amount dy the extra flux through the strip will be $2I dy\,dx/x$.

But if this increase in the length of the strip is effected by a stretching of the vertical conductors due to a downward movement of the horizontal conductor that joins them, the amount of flux cut by the portion of the moving conductor that crosses the vertical strip will be only

$$I\,dy\,dx/x \qquad \text{......(11)};$$

for, as we have proved, the flux density at x is only I/x. This holds good for all values of x that are not less than the radius of the vertical conductor but are very small in comparison with h. In cases where the flux inside the vertical conductors is negligible, then, the amount of flux cut by the moving conductor is approximately half the amount of extra flux that links the loop as a result of the movement.

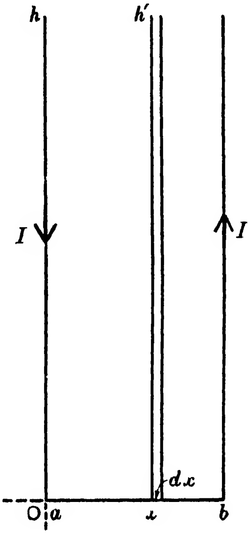


Fig. 3

Let us now consider the flux inside one of the vertical conductors (of non-magnetic material), assuming that the current I in this conductor is uniformly distributed over the cross-section. In accordance with what has already been said, the average flux density at a radial distance x will be $2\,(Ix^2/r^2)/x$; for Ix^2/r^2 will be the current traversing the central portion whose radius is x. Between the radial distances x and $x + dx$, then, the flux per centimetre length of the conductor will be $d\phi = 2I\,(x/r^2)\,dx$. This flux surrounds a current of Ix^2/r^2, and therefore represents a store of magnetic energy equal to

$$\tfrac{1}{2}\,(I^2x^4/r^4)\,dL = \tfrac{1}{2}\,(Ix^2/r^2)\,d\phi = I^2\,(x^3/r^4)\,dx.$$

By integrating from $x = 0$ to $x = r$, we get $I^2\,(\tfrac{1}{4})$ as the store of magnetic energy (per centimetre length) due to the flux inside each conductor. Consequently, when the loop is stretched through the distance dy by the movement of the horizontal conductor, the mechanical work due to the flux inside the two vertical conductors is $2I^2\,(\tfrac{1}{4})\,dy$, and the force is $I^2\,(\tfrac{1}{2})$.

We thus see that, no matter whether we do or do not have to consider the flux inside the vertical conductors, formula (10) indicates only about half the actual force; and, as already mentioned, this conclusion has been verified experimentally.

It is possible, however, to obtain a convenient and accurate formula by modifying (10) in the way that the above considerations have shown to be necessary. Supposing that

$$\sqrt{\left(\frac{r}{h}\right)^2 + 1}$$

is very nearly 1, as it almost always is, in practice, the alteration of the 0·25 to 0·5 will make (10) correct as regards the flux linkage inside the conductors. To make it correct as regards the flux linkage outside, we must use the flux through a rectangle having a breadth of dy and stretching across the middle of the vertical conductors, instead of the flux through a similar rectangle at the bottom, that is to say, instead of $lgn\; b/r$, we must have

$$2\;lgn \frac{2b/r}{\sqrt{\left(\frac{b}{\frac{1}{2}h}\right)^2 + 1} + 1}\;*.$$

Further, instead of adding $2\,(0{\cdot}25)$ to the expression just arrived at, we may notice that $0{\cdot}25$ is approximately $lgn\;1{\cdot}28$, thus getting the following neat formula

$$F = 2I^2\,lgn \frac{2{\cdot}56\;b/r}{\sqrt{\left(\frac{b}{\frac{1}{2}h}\right)^2 + 1} + 1} \qquad \text{......(10 }a\text{)}.$$

* This is easily obtained by putting $J = I$, $\sin u = 1$ and $c = 0$ in (8), and then integrating.

This is better than (9 *b*), since it takes more accurate account of the flux inside the conductors. But the two formulae usually give about the same result, and the results are practically identical in the cases where (9 *b*) was verified by tests.

IV. The True Law of Electromagnetic Induction

The above considerations enable us to settle an old dispute with regard to the law of electromagnetic induction. According to one view, the electromotive force induced by the downward movement of the horizontal conductor in Fig. 3 is equal to the rate at which this conductor is cutting the magnetic flux due to the current in the vertical conductors, supposing that the rest of the circuit is too far away to have any appreciable effect. According to the other view, the induced electromotive force is equal to the rate at which the flux linkage is being increased. One of these views must be wrong; for we have seen that the former rate may be much less than the latter.

Taking a case in which b is very great in comparison with r and very small in comparison with h, and remembering that there are two vertical conductors, we see that the flux cut by the moving conductor is twice the integral of (11), from $x = r$ to $x = b$, and that the increase in the flux linkage is twice as great as this. The increase in the flux linkage is accordingly

$$I\,dL = 4I\,dy\,\mathrm{lgn}\,b/r \qquad \text{......(12).}$$

But, in order that the current may be kept constant in spite of the electromotive force induced, we must have a corresponding increase in the electromotive force applied. Supposing that the movement takes place with uniform velocity in one second, one of the above views would tell us that the induced electromotive force is $I\,dL$, and that $I^2\,dL$ therefore represents both the extra power and the extra energy due to the required increase in the electromotive force applied. Half of this extra electric energy is expended in increasing the stored magnetic energy; for we know that the increase in this store of energy is $\frac{1}{2}I^2\,dL$. The mechanical work done must therefore represent the other half of the extra electric energy, so that (if F is the force on the horizontal conductor)

$$F\,dy = \tfrac{1}{2}I^2\,dL = 2I^2\,dy\,\mathrm{lgn}\,b/r,$$

therefore

$$F = 2I^2\,\mathrm{lgn}\,b/r \qquad \text{......(13).}$$

The forces measured in the above-mentioned laboratory tests were merely a matter of 7 or 8 per cent. below those given by this formula. The tests therefore confirmed the view that we are here considering, and contradicted the other view: the measured forces were naturally somewhat less than those indicated by the formula, since this formula assumes that b/h is much smaller than it was in the test apparatus.

MEASUREMENT OF THE FLOW OF HEAT.

By A. F. DUFTON, M.A., D.I.C. The Building Research Station.

[*MS. received*, 31*st May*, 1927.]

ABSTRACT. A method of recording the flow of heat across the surface of a wall is described and illustrated.

1. For a comparison of the transmission of heat through various structures under different weather conditions it is desirable to measure the flow of heat across the surface of a wall. Two methods of measurement have hitherto been employed. In the first method, described by Barker*, 10 sq. ft. of the wall are covered with an insulated box and heat is supplied to

* *Univ. of London, Dept. of H. and V. Eng.* Bulletin No. 2 (1918).

maintain the air in the box at the same temperature as that in the room. This method is inaccurate unless the temperatures of the covered and uncovered surfaces are the same. In the second method, due to Nicholls*, the heat transmission is deduced from the temperature gradient in a layer of material applied to 4 sq. ft. of the surface of the wall. This has the disadvantage that the added resistance and changed nature of the surface affect the flow of heat.

2. In the method here described, the flow of heat is determined by applying to 1 sq. ft. of the surface an electrically heated plate backed with cork (Fig. 1) and measuring the power required to maintain the surface under the plate at the temperature of the uncovered surface. This temperature regulation is effected by a system of four thermocouples, embedded in the

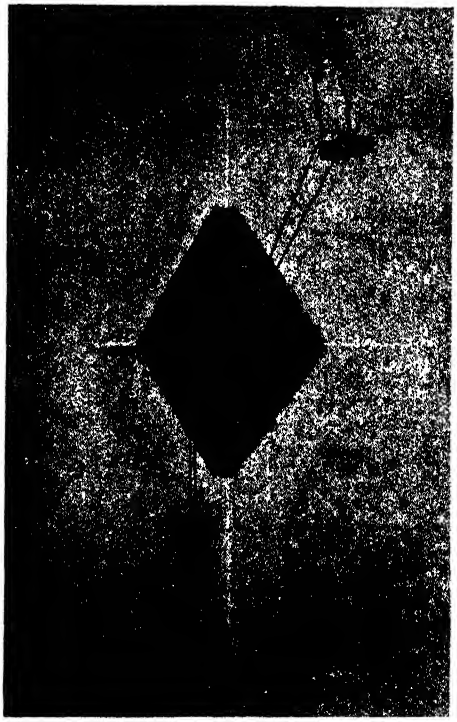


Fig. 1

surface of the wall, in conjunction with a cascade of relays controlling the electricity supply. The primary relay, which was made by the Cambridge Instrument Company†, requires one micro-micro-watt for operation. The plate is a sheet of Wood's alloy in which is embedded a grid of insulated wire. It is backed with cork $1\frac{1}{4}$ in. thick and secured to the wall with shellac.

The power supplied to the plate is recorded by a novel meter. This comprises a tin containing cotton wool in which is embedded a thermocouple, one junction of which is surrounded by a resistance coil. The resistance coil carries a portion of the electricity supply and the thermocouple leads are connected to a recording galvanometer.

Thermocouples with junctions in the cork backing to the plate add to the recorded power the small contribution due to heat conducted through the cork. It is expedient to calibrate

* *Journn. Amer. Soc. H. and V. Eng.* **30** (1924).

† Instrument No. L 18997.

these by supplying power to the plate when temporarily faced with an equal thickness of cork.

3. Fig. 2 is a record of the flow of heat across 1 sq. foot of the surface of the wall. The lower half of the record shows the temperature difference between the air and the wall surface.

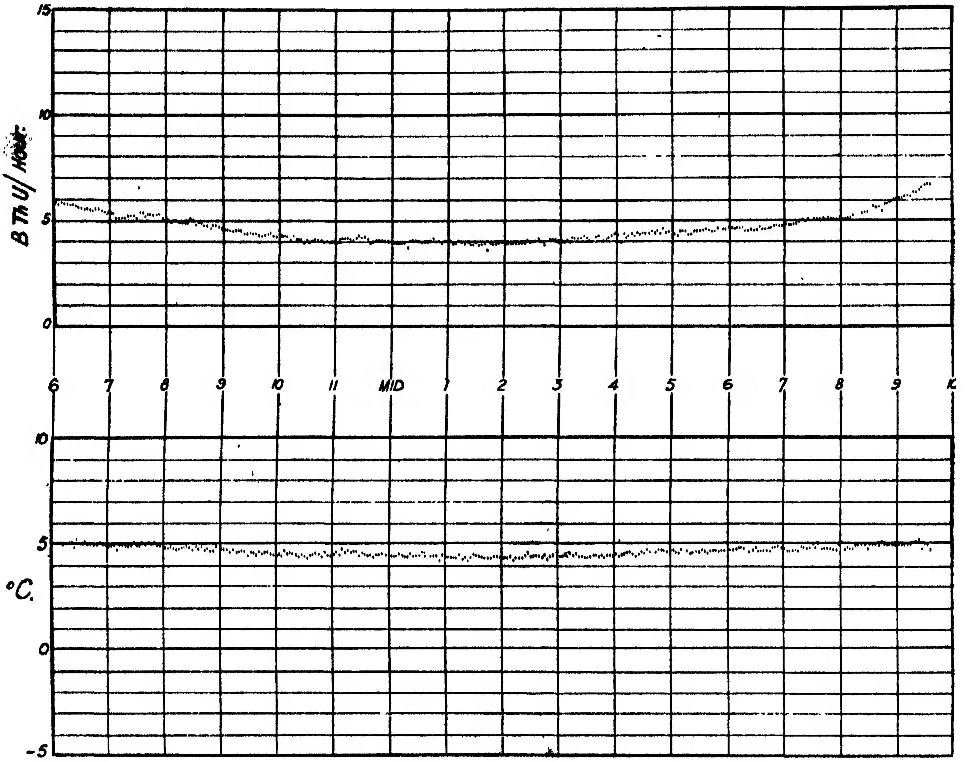


Fig. 2

THE INSPECTION AND MAINTENANCE OF THE THERMOCOUPLE PYROMETER INSTALLATIONS IN WORKS AND LABORATORIES.

By A. BLACKIE, M.A., F.Inst.P. and C. W. OCKELFORD, H.M. Fuel Research Station. (Communication from the Director of Fuel Research.)

[*MS. received, 2nd August, 1927.*]

The use of thermocouple pyrometers in works and laboratories has greatly increased in recent years owing to the necessity for accurate temperature control in industrial processes. In order that full advantage may be obtained from such temperature indications and control, it is necessary to ensure not only that the pyrometers should be correct when installed, but that they should be maintained in that condition. To maintain any pyrometer outfit in perfect condition, an organised system of inspection and tests is necessary, and it is thought

that the following scheme, which has been adopted at H.M. Fuel Research Station as the result of several years' experience with various types of commercial pyrometer outfits, will be of interest. Details of carrying out the various tests are not given as they can be found in the text-books.

The various instruments can be divided into two classes, "Laboratory" and "Works"; laboratory apparatus being of greater accuracy than is necessary, or in many cases possible, in works practice. The pyrometer outfit consists of three main portions: (*a*) the actual thermocouple, (*b*) the indicating or recording instrument, and (*c*) the connecting leads between (*a*) and (*b*).

Inspection of new apparatus.

On receipt from the makers, the thermocouples are standardised at a number of fixed temperatures, with an additional check over the range 0–50° C. for cold junction correction purposes. The resulting readings on the indicators or recorders supplied, and the open circuit E.M.F.'s as measured on a potentiometer, are entered up, and form a record of the outfits as received. From this record the Temperature/E.M.F. curves are plotted, and any differences from the figures or graphs supplied by the makers are noted.

The millivoltmeters and recorders are tested by means of a potentiometer. Their internal resistances are also measured. The connecting leads, switches, etc. are tested for conductivity and insulation.

The above-mentioned tests are carried out before the outfits are installed in their working positions, as it is impossible in many cases to carry out such tests, with the completeness and accuracy desired, after installation. Full records of the results are preserved for comparison with subsequent routine tests, so that any defects that may develop can be noticed at once.

Laboratory Type Thermocouples.

Thermocouples for use in the laboratory are generally made up at the Fuel Research Station from a large consignment of wire. Samples from the wires are made into couples, which are standardised and preserved as sub-standards against which other couples from the same batch of wire can be tested. Each laboratory couple bears a label giving the date of the last comparison with the sub-standard, and those in constant use should be tested at least every four weeks.

Routine testing of "Works" couples.

The removal of couples from the fixed positions for subsequent checking would entail a large amount of work. To avoid as much as possible any disturbance of the various outfits, special testing couples, of laboratory type, are kept for taking temperature readings on the actual site, the normal couple and the test couple being inserted together if possible; otherwise the normal couple is withdrawn to permit the test couple being placed in the exact position required. Particular care should be taken to ensure that the hot junction of the test couple is in the same temperature zone as the working couple, otherwise comparison is useless. Any couples found to be defective can then be dealt with as desired.

The testing of leads for conductivity and insulation should be carried out at the same time. These tests show, by any variation from the original figures, the possibility of damage to wires or insulation before actual breakdown occurs.

This system of testing should remove any doubts as to the indications shown by the various outfits, and ensure their being kept in good working condition.

Causes of incorrect readings.

Past experience with faults on "Works" outfits has shown that main causes of incorrect readings are as follows:

(1) Line faults; loose and dirty contacts, etc., insulation defects.
(2) Breaking of hot junctions in wire type couples.
(3) Ageing of instruments and loss of sensitivity.
(4) Variations from original Temperature/E.M.F. ratio of the couple.

The first is by far the most common cause of trouble. Investigations of actual cases make it evident that as a rule the defects are brought about by accidental damage. It considered that, as far as practicable, all leads should be enclosed in conduits and permanent connections should be made.

A concentric system of compensating connecting lead, consisting of a soft metal tube encasing an insulated centre wire of heavy cross-section, is also to be recommended where this system is suitable, and an earthed return circuit permissible.

Faults under (2) should be rare. Frequent faults under this heading, apart from accidental breakages, would indicate that unsuitable materials for the particular application have been used for the construction of the couples. It should be noted that where a particular type of couple is recommended for use at a certain temperature, it by no means follows that this same couple is suitable for use at lower temperatures. Certain base metal couples that will give quite good service at say 900° C. may fail, due to breakages, when used continuously at temperatures of 700° C. and not taken to the higher temperature, owing to one or other of the couple components having a smaller mechanical strength at this temperature than it has at temperatures slightly above or below it.

Faults under section (3) are very rare; in fact only one case has been met with during the past six years.

Faults under section (4) are also very rare. The couples in use have shown extraordinary consistency, retaining their original Temperature/E.M.F. ratio until they are practically burned through.

Periods of test.

(1) To keep watch on the occurrence of such faults as have been referred to, each installation should be tested at least once in three months.

(2) In addition, the following points should be inspected sufficiently often to ensure that no part of any system is unobserved for more than 14 days. On plant that is in continual use the pyrometers, etc., should be inspected more frequently.

(*a*) Zero setting of instruments.

(*b*) Tightness and cleanliness of all joints and connections.

(*c*) State of the whole installation with a view to signs of damage that may later result in a "fault."

In addition to the foregoing system of inspection and testing it will usually be necessary to issue strict rules forbidding interference with any installations by unauthorised persons. To this end it is advisable that the indicators be fitted in locked cases. Arrangements should be made for the immediate report of any failure or defect and also of any suspicious readings.

With these precautions, it has been found from experience that there is no reason why an installation by any one of the recognised makers should not retain its original accuracy for many years. The only parts of an installation which are subject to "wear and tear" are the thermocouples themselves, and these should be replaced from time to time as they burn away.

THE OCEAN TRANSPORT OF FRUIT

A FACTOR which is of fundamental importance to the prosperity of industrial Britain is that of food transport. Certain of our overseas dominions are particularly favoured for the growth of agricultural produce far in excess of their local requirements, so the problem is to devise an efficient system of transport overseas and sometimes overland as well.

It is generally acknowledged that as a method of food preservation, refrigeration is the one which causes the minimum of change in the desirable properties of fresh fruit. Hence refrigeration has become a factor of immense potentiality for the transport industry. The application of refrigeration to cargoes in bulk is now being extensively practised, and it has been found that this industry presents many perplexing problems owing to the delicate nature of the products dealt with. An apple, for instance, is a relatively robust fruit, but it is a living organism subject to disease and sensitive to maltreatment. Grapes and peaches need yet greater care in handling.

Under the auspices of the Union Government of South Africa a thorough scientific investigation has been made of problems of fruit transport, for the industry is of primary importance to that country. South Africa, by virtue of its climatic and geographical position, enjoys the unique advantage of having its fruit harvests occur at a seasonal period when the European market is barren of competitive produce. She produces the most delicate and expensive varieties of fruit; grapes, peaches, plums, nectarines, grenadillas and persimmons figure in the list of exports, so that it will be realised that the safe carriage of such produce overseas, for a distance of 6000 miles through the intense heat of the tropics, is no mean undertaking.

A detailed investigation was made by the authors of this report* into the capabilities of the refrigerating systems employed, under actual working conditions, and this section of the report is worthy of deep study by all interested in refrigeration. In the present review it is proposed to consider especially the instrumental problems involved. It might be remarked that the present report indicates the need for further developments in equipment for marine work, and suggests the possibility of designing apparatus which will be portable and which will give the engineers the information necessary to ensure the safety of the cargo.

The time-honoured method of determining the temperature of the hold on board ship is to use thermometers suspended from lengths of string; and during every watch the thermometers are pulled up on deck and the readings logged. Experiment showed that these thermometers indicated neither the actual fruit temperature nor did they show the true gradient from top to bottom. This is due to the fact that the thermometers are situated in a vertical cavity in which convection currents can circulate. To obtain accurate data distant reading thermometers were installed; these were of the electrical resistance type.

The investigators found that many peculiar difficulties arise, even when the most robust type of land instrument is installed on board ship. The movement of the ship in heavy seas demands the maximum damping. The temperature conditions are severe; in the space where the recorders had to be installed the temperature sometimes reached 130° F., and this proved very trying both to the electrical portion and to the clockwork, as lubrication became unsatisfactory. After trying every known type of recorder the authors came to the conclusion that not one of them could be installed on board ship and the record guaranteed correct to ± 1° F. for long periods.

* "Ocean Transport of Fruit under Refrigeration from South Africa." By Edgar A. Griffiths and R. Davies, *Science Bulletin*, No. 56. Dept. of Agriculture, Union of S. Africa. Cape Times, Ltd., Cape Town.

The estimation of the products of respiration is next in importance to the measurement of temperature, for if the carbon dioxide is allowed to accumulate it exerts a strong toxic action, and long before it has replaced the entire oxygen supply, the presence of carbon dioxide may actually kill the fruit. The authors tested a number of carbon dioxide measuring instruments, and they give an interesting account of the ailments to which the various types are subject. This information should prove invaluable to those who, in the course of their work, have to select and keep in working order recording instruments for the measurement of carbon dioxide.

In the report is described a portable form of carbon dioxide instrument based on the diffusion principle. This instrument can be dropped down a thermometer tube and withdrawn for reading. Electrical CO_2 indicators, based on the different thermal conductivities of various gases, were examined, representative instruments of British and Continental manufacture being studied. It is pointed out that volatile vapour products from fruit may have a disturbing influence on the readings. Mechanical CO_2 indicators, based on the fact that the density of carbon dioxide-air mixtures is greater than that of air, are described, and it is pointed out that instruments of this class have advantages for marine use, but improvements of detail are suggested.

The Rayleigh interferometer method of measuring carbon dioxide was successfully used under the trying conditions prevailing on board ship. The remarkable feature is the sensitivity: 1 per cent. of CO_2 caused a change of one part in a million in the refractive index, and readings could be made to 0·1 per cent.

As regards humidity, it is pointed out that the optimum value of the humidity for different varieties of fruit has not yet been established, and all that is known is somewhat meagre generalisation with regard to pears, citrus fruit and grapes; but extensive experiments are in progress on this subject.

While the study of instruments was only incidental to the main enquiry, it constitutes a most valuable section of the report. The document is admirably illustrated by a large number of drawings and photographs.

NEW INSTRUMENTS

OUTPUT TRANSFORMERS FOR LOUD SPEAKERS

A HIGH efficiency distortionless transformer is very desirable at the output end of a radio set, especially when large power valves are used, in order to avoid risk of damaging the windings, demagnetising the magnets or upsetting the adjustment of the polarised telephone

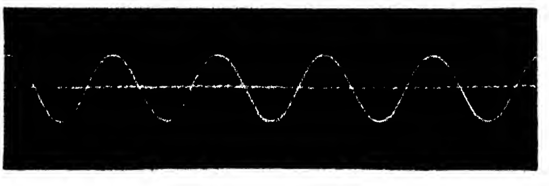


Fig. 1. The input wave

or loud speaker movement. Messrs Ferranti Ltd. of Hollinwood, Lancashire, have recently introduced two types of output transformers, one with equal ratio (O.P. 1) and the other with a ratio of 25 to 1 (O.P. 2) which they claim are quite distortionless over the whole frequency scale from 100 to 8000, even with plate currents up to 40 milli-amperes. Figs. 1 and 2 show the input and output wave forms of one of these transformers taken with a

cathode-ray oscillograph, with a plate current of 30 milli-amperes, and indicate an entire absence of distortion. It is stated that the measured amplification of a power valve, with

Fig. 2. The output wave

this type of transformer connected to a loud speaker, is only 6 or 7 per cent. less than if the loud speaker is connected directly to the valve, over the whole of the above frequency range.

MICROSCOPE APPLIANCES

From Messrs Ogilvy and Co. of 20 Mortimer Street, London, W. 1, we have received two pamphlets, relating to the Akehurst-Ogilvy sub-stage condenser changer (Fig. 1) and to the Dickinson micro-isolator. In the former device each condenser is mounted on a bevelled metal slide which can be slipped into guides on a ring mounted on the ordinary sub-stage holder. It is claimed that these condenser fittings can be made accurately centred and interchangeable without the need for adjustable centring screws. The firm have also adopted the three-point objective centring clutch of Messrs Leitz (Fig. 2), for permanently centring the objective to the microscope tube, the first adjustment of the objective being made by box keys, after which it is said to remain

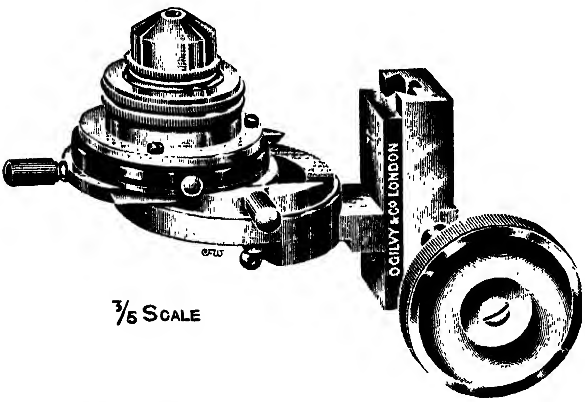


Fig. 1. Akehurst-Ogilvy condenser changer

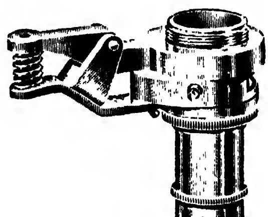


Fig. 2. Leitz three-point objective centring clutch

permanent. The micro-isolator devised by Mr Sydney Dickinson (Fig. 3) of the Rothampstead Experimental Station is an ingenious device for isolating and removing any desired micro-organism from a collection. It operates on the principle of surface tension. On a sterilised thinly agar-coated cover slip a few spores or bacteria are placed, and the slip is placed with the agar surface downwards on a van Tieghem drop cell, allowing a fine glass rod to be applied to the surface from below while under the microscope.

The rod is first made to touch the surface near the edge, then slightly withdrawn and moved across it, causing the bacteria to be left behind in a streak of fairly widely separated individuals. The rod is then withdrawn, and when the particular cell which it is desired to remove has been selected the rod is brought again into contact with the surface near to it, and withdrawn until the water adhering to it is drawn into a neck. On traversing the rod to the edge of the slip the bacterium

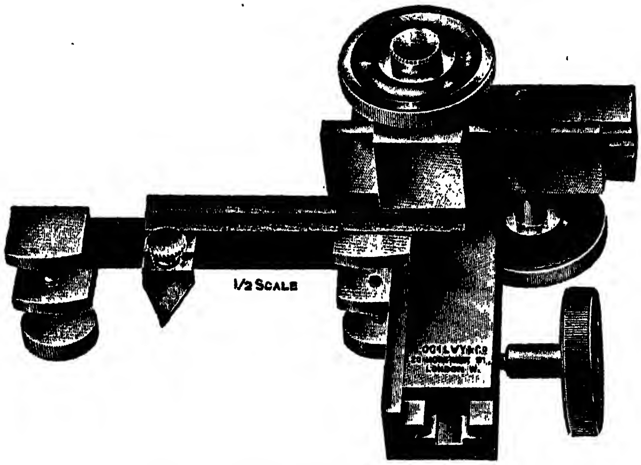


Fig. 3. Dickinson micro-isolator

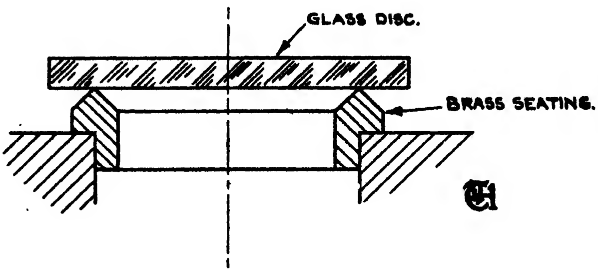
remains in the drop and is carried along with it, so that when the rod is removed the bacterium is isolated at the edge of the film, which can be cut away and transferred to the culture medium.

Two forms of this isolator are made, one, as shown, being for attachment to the microscope stage, and the other mounted on a base on which the microscope can be clamped.

LABORATORY AND WORKSHOP NOTES

A GLASS AND BRASS VALVE

THE figure illustrates a very simple yet efficient type of valve which was designed by Mr William Taylor some years ago. Essentially the valve comprises a disc, cut from ordinary plate glass, which lies on a "knife edge" seating, a piece of ground glass being used to "grind" the seating to a true plane.



This valve is suitable for use with liquids or gases, and has the advantages of being easily constructed, of having no perishable parts, and of not being easily fouled by dirt. Originally the valve was designed for use as a control valve in connection with a thermostatic appliance, but it has since been applied to a diversity of purposes with considerable success.

THE TAYLOR-HOBSON RESEARCH LABORATORY, LEICESTER.

PURIFICATION OF RARE GASES AND "CLEAR UP" BY SODIUM. By JAMES TAYLOR, D.Sc., Ph.D., A.Inst.P.

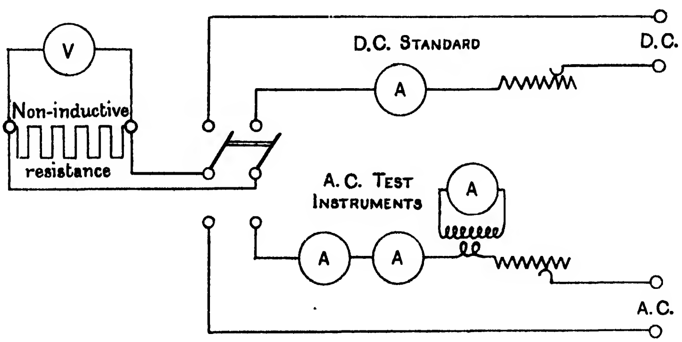
It is often necessary to purify rare gases by removal of the active gas impurities. Soddy's heated calcium method, or a calcium arc, are frequently used. The present writer has sometimes utilised the method of introducing sodium electrolytically, through a side tube attached to the gas reservoir. The method has been described in this *Journal* (vol. 4, No. 3, December 1926).

An ordinary 10 volt half-watt lamp may be improvised for the purpose, and it is a matter of comparative simplicity to blow a thin sodium-glass extension on to the bulb, so that sodium may be introduced fairly rapidly. Sodium glass is not essential, but gives better results. The method is effective in removing oxygen, but in the case of hydrogen, and to a lesser extent oxygen, the dissociation pressure of the compound at the temperature of the molten sodium nitrate (about 330° C.) is sufficiently great to prevent the action proceeding to pressures of less than a few bars, and there is additionally a certain decomposition by the cathode rays.

When sufficient sodium has been introduced in this way, the action may be stopped and the tube allowed to cool. The clear up of the gas impurities then continues, though slowly. The method may be applied as well for the clear up of residual gases in evacuated vessels, and for the making of mercury vapour traps.

CHECKING A.C. AMMETERS. By E. H. W. BANNER, M.Sc., A.M.I.E.E., A.Inst.P.

It may happen that standard A.C. ammeters of known accuracy are not available for the purpose of checking the calibration of ammeters of the moving-iron, induction, or dynamometer types. A substitution method, relying only on the calibration of a moving-coil ammeter of the same or higher range than the test instrument, is applicable and permissible. A voltmeter, suitable for D.C. or A.C., is also required, but its calibration is unimportant, as it is not used as a voltmeter, but as an indicator only. This indicator may be a dynamometer, an electrostatic voltmeter or a thermal vacuo-junction with a D.C. millivoltmeter.



A non-inductive resistance is necessary, which will carry the full current needed for the test ammeter, but the temperature error, if any, is of no consequence. Its resistance should be such as to give a reading on the voltmeter of nearly full scale with the full current passing. A source of D.C. is needed for comparison, and a moving-coil ammeter of range equal to or greater than the test instrument, and of accuracy at least as high as that at which the latter is to be tested. A sub-standard will fulfil nearly all requirements.

The figure shows the circuit used. It will be seen that the resistance, with the voltmeter permanently across it, carries either D.C. or A.C. at will, by means of the change-over switch. There may be any number of ammeters in series, with or without current transformers. If transformers are used, the combination is tested together. For operation, D.C. is first switched on and adjusted to a convenient low value, the voltmeter reading is then noted and the switch quickly changed over, and the A.C. adjusted until the voltmeter reading is the same as before. A rapid change back to D.C. is advisable as a check and then the ammeter reading is taken on A.C. again. The process is repeated at a number of points until the whole range is covered.

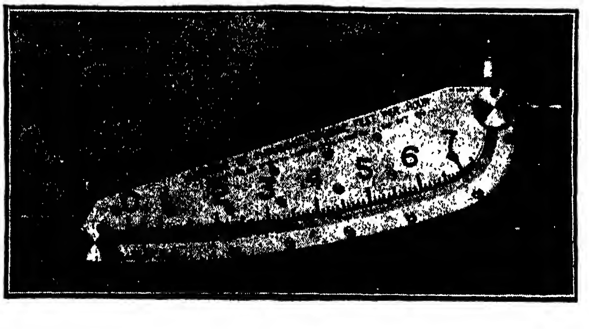
An alternative plan is to calibrate the resistance by plotting a curve connecting D.C. volts and amperes, taking the readings only when the instrument readings are steady, in order to allow for the temperature change. For subsequent A.C. calibrations the A.C. ammeters are connected and A.C. used. Further readings of volts and ammeter readings are made when steady, and from the first curve the "volt" readings of the second test are converted to true current readings for direct comparison. The voltmeter and resistances should be undisturbed between calibration and use. This latter plan is most useful if the controlling rheostats are of coarse adjustment only.

All ranges of ammeters may be checked by these methods, but they are most suitable for relatively high ranges, where a large accurate non-inductive resistance, free from temperature error, is cumbersome and expensive. It is, of course, presumed that a standard A.C. ammeter is not available for direct comparison.

CORRESPONDENCE

CURVED TUBE MANOMETER

THE interesting method described in your September issue by Mr W. J. Duncan, B.Sc., of the National Physical Laboratory, in which changes of surface tension with temperature are balanced against changes of volume, so as to secure on a sensitive manometer a zero which is relatively unaffected by temperature changes, is one which I have used* for many years on the Curved Tube Manometer shown in the accompanying figure.



In this instrument the surface area of the metal reservoir, which is behind the scale shown, is made so as to compensate for surface tension effects when the meniscus is at the zero of the instrument, where the gauge tube has a standard slope of 2°. The instrument

* See Patent No. 6188/23.

illustrated is quite as sensitive as the Chattock Gauge, is considerably cheaper, and has the advantage that it gives instantaneous readings over a large range of heads.

The gauge tube is bent to such a curvature that an equal spacing flow or velocity scale is obtained in those cases where the flow or velocity varies as the square root of the head. The gauge tube is made of celluloid, so that it is unbreakable, and is of rectangular section, with a white reflecting surface at the top, so that the meniscus is very easily seen and read.

JOHN L. HODGSON.

MESSRS GEORGE KENT, LTD.
BISCOT ROAD WORKS, LUTON.

THE THERMAL AMPLIFICATION OF GALVANOMETER DEFLECTIONS

In this *Journal*, vol. 4, p. 4, 1926, I gave a short account of experiments with the method of Moll and Burger for amplifying galvanometer movements by means of a thermal relay. In proposing this method Moll and Burger were anticipated by Wm Hamilton Wilson, who, with Miss Epps, suggested the same device in a paper "The Construction of Thermocouples by Electrodeposition," published in the *Proceedings of the Physical Society of London*, vol. 32, p. 328, 1920; and Mr Wilson tells me that the device was patented in a Specification No. 144757 of 1919 (see below).

He states also that the idea of using differentially connected thermocouples in circuit with a galvanometer, to register minute deflections of another galvanometer, occurred to him about 1913, when he tried to carry it out in practice. The junctions he was then able to construct were, however, not very sensitive, so that it was not until 1919, when he had devised a method of making them by electrodeposition, that he got the arrangement to work effectively. This valuable method of amplifying galvanometer and other movements was therefore invented by Wm Hamilton Wilson long before it was described by Moll and Burger.

A. V. HILL.

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GOWER STREET, W.C. 2.

Extract from Patent Specification No. 144,757, 1919.

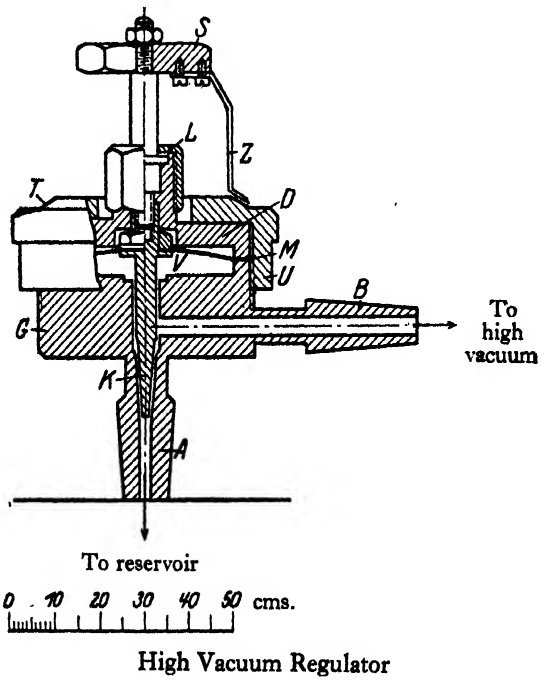
"A similar line of junctions may be combined with any known reflecting galvanometer or like instrument, which is adapted to reflect the heat of a lamp filament or the like upon the thermopile. Two such line piles, placed close beside and nearly parallel to one another, will suffice to make apparent in a local electric circuit a very minute deflection of the reflecting instrument. For instance, if the two lines of junctions are about 1 mm. apart, and the instrument lamp is so placed that its reflection extends over substantially the whole length of the two sets of junctions and is equally inclined to them, a deflection of 1 mm., plus the width of the reflected image, will suffice to carry the image from a position in which it heats one set of junctions alone to a position in which it heats the other set alone; and the resultant change in current in the thermopile circuit may suffice to deflect another instrument over a very wide range; the sensitiveness of an instrument may thus in effect be multiplied hundreds of times. Alternatively two piles may be placed in line with one another, so as to form a single line of junctions, of which one half is in opposition to the other, in a local circuit; and the lamp filament may be placed parallel to the plane of rotation of the galvanometer mirror; so that its image lies along the line of junctions covering say half an inch or an inch of the line. The thermo-electric current generated in the local circuit may thus be made substantially proportional to the deflection of the galvanometer."

CONTEMPORARY PUBLICATION

Zeitschrift für Instrumentenkunde. *September*, 1927

An exhaustive mathematical treatment of the right-angled prism with silvered hypothenuse is given by Dr Franc Schultze for the special case when the incident light is approximately parallel to the hypothenuse and is reflected twice at the perpendicular face and the hypothenuse before emergence at right angles to its original direction. The prism, when used in this manner, acts as a plane mirror at 45°, but without perversion of the light, and is spoken of as a "Bauernfeindschen" prism. Karl Lüdemann gives a series of measurements and analyses of the errors of the circles in three small theodolites made by Hildebrand, Zeiss, and Wild, with diameters of 80, 75, and 95 mm. respectively. The results show the amplitude of the errors to be only about 0·25 second in the Hildebrand and Wild instruments, and about 1 second in the Zeiss form, the corresponding linear errors in the dividing being only about ·04 to ·25 thousandths of a millimetre.

A form of high vacuum regulator free from grease or mercury, based on the Bodenstein regulator but without employing platinum or other costly materials, is described by Bernhard Josephy (Fig. 1). The diaphragm M is a curved nickel disc, 1/10 mm. thick, drilled through its centre and tightly clamped on the spindle of the cone K by means of a nut and two thin lead washers. The diaphragm is tightly clamped between the upper and lower portions of the housing D and G by the screwed cover T, and the upper housing carries a boss the middle of which is drilled to receive the upper end of the cone spindle, and also a coaxial spindle with hexagonal head S and a flange L which is held by a cap nut, but is free to turn. As the lower end of this spindle is screwed and enters into the end of the cone spindle, turning the head S causes the cone to be raised or lowered, and therefore to open or close the conical aperture A, the opening being indicated by the pointer Z on a scale on T. The cone, screw spindle and body are of Siemens-Martin steel and the cover plate and pointer Z of brass. The device can be employed without any grease, and suffers very little from corrosive gases. As an example, with a pressure of 60 mm. of chlorine gas in a reservoir the flow of gas could be varied between $3{\cdot}5 \times 10^{-5}$ gram/sec. and $1{\cdot}7 \times 10^{-2}$ gram/sec. It has worked satisfactorily for weeks with chlorine or bromine gas.



High Vacuum Regulator

The best conditions and sensitivity of the Piram and Carey-Foster method of comparing a mutual inductance with a capacity is discussed by Morton Masius, leading to the conclusion that the ratio of the resistances of the primary and secondary circuits of the inductance should be equal to that of the two resistance coils, and that in this case the accuracy of the method may be within 0·2 per cent.

A history of the development and manufactures of the firm J. and A. Bosch of Strasburg is contributed by W. Kiel; and Prof. Dr H. Opitz discusses the variation of the ratio of partial to total dispersion with change of the angle of incidence of the light.

The death of Dr Carl Pulfrich of Jena, which occurred on the 12th August as the number was going to press, will be lamented throughout the scientific world. He was one of the editors of the *Zeitschrift*, and this issue contains a note from him on the production of a pure spectrum by means of the limiting line of total reflection, a method which has recently been put forward by Dr R. Richter, but which Dr Pulfrich had already described in the Zeiss publications 30 years ago.

REVIEWS

Calculus. By H. B. PHILLIPS, PH.D., Associate-Professor of Mathematics in the Massachusetts Institute of Technology. (London: Chapman and Hall, Ltd., 1927. Pp. 352. Price 15*s*. net.)

To the experimental physicist who is not concerned either with the foundations of mathematics or with its logical niceties, but who desires a good working knowledge of the infinitesimal and integral calculus, the present volume should be eminently satisfactory. It covers the usual field up to double and triple integration, and includes an elementary treatment of some of the so-called standard forms of ordinary differential equations, embracing differential equations with constant coefficients.

The examples are numerous, well chosen and varied, with a distinct bias towards applications of a dynamical and physical nature. From the standpoint of the mathematician, however, the author has undoubtedly over-simplified the subject, minimising the difficulties and ignoring the limitations of his proofs. The method of presentation, in fact, is old-fashioned, and does not differ from that developed in text-books written nearly a generation ago. While a student who could master its contents would attain a high degree of proficiency in manipulation he would be utterly ignorant of the fact that the underlying basis of the calculus has been completely revolutionised during the past two decades.

H. L.

The National Physical Laboratory. Report for 1926. H.M. Stationery Office. Pp. 260. Price 7*s*. 6*d*.

(*Continued from page* 429)

METROLOGY DEPARTMENT

Contact rusting. When two flat steel surfaces in intimate contact are moved one over the other a deposit of rust is subsequently produced between them. Previous explanations have been that this effect is due either to electrolysis or to intense surface heating caused by friction, but it has now been found that the rust is due to the instantaneous oxidation of molecules torn from the metal surface by molecular cohesion. A film of castor oil prevents rusting to some extent, but in wringing plane surfaces together the high spots may cause perforation of the oil film, and no really reliable way of avoiding rusting has yet been found.

Block gauges of 4-inch length have been measured in terms of light waves. The spectrum lines used for this purpose are two which are given by glowing krypton and which give interference over a path of 8 inches. Comparative mechanical measurements in terms of the Imperial standard yard showed agreement to a millionth of an inch.

Contact between flat surfaces with oil film interposed. A film of paraffin oil of known weight was wrung between two *polished* flat surfaces and the average thickness of the film obtained from the weight, area, and density: the value 6×10^{-7} cm. was found, agreeing roughly with the minimum thickness found in the black spot of a soap bubble by Johonnot. When *lapped* surfaces were used no increase in length was found when an oil film was present. Apparently the high spots come into absolute contact and the liquid merely fills up the fine lapping scratches: the force of adhesion is however increased, probably because the oil film provides a connecting link between the low spots.

In the search for materials suitable for *secondary standards of mass* nichrome (80 per cent. Ni 20 per cent. Cr) has proved the most satisfactory substance so far investigated. Two 100-grm. nichrome weights have remained constant over the course of a year to 5 millionths of a gramme. *A 200-grm. balance with a beam of invar steel* has been under observation for two years: it was expected that it would be less affected by temperature changes than chemical balances of ordinary design: actually the use of invar does not seem to confer any greater temperature accuracy.

A number of *1st quality diffraction gratings*, both plane and curved, the largest being 8 cm. $\times$ 5 cm. have been ruled. Much difficulty is still experienced in ruling 3-metre gratings of large aperture: this is largely due to variations in the effective cutting angle of the ruling diamond as it travels across the concave speculum.

Jewel bearings. It has been found that the efficiency of a jewel depends on the direction in which it is cut relative to the crystal axes of the material.

ENGINEERING DEPARTMENT

Fluid friction and heat transmission. The extremely high values of the frictional resistance exhibited by the surface of a deeply corrugated copper pipe raised the question whether in such a case the heat transmission would be increased in a corresponding ratio, as would be inferred from the Reynolds' law of heat transmission. It was decided, therefore, to attempt the determination of the heat transmitted by the pipe in which the friction tests had been made. For this purpose the pipe was surrounded by a jacket through which steam was circulated.

Cold water was passed through the corrugated pipe at a known rate, and from the rise of temperature of the water and a knowledge of the surface temperature of the pipe the coefficient of heat transmission could be determined. The results indicated that although the variation of heat transmission with velocity approximately followed Reynolds' law, the numerical factor given by the experimental results differed widely from the theoretical. It would seem therefore that the law does not apply to momentum losses in the fluid due to eddies of considerable magnitude.

Endurance tests on laminated springs. A comparison was made of the resistance to repeated loadings of laminated springs made of alloy steels with those of carbon steel: the alloy steels showed no decided superiority.

Rust prevention. Steel test bars, some coated with lanoline, some with rectified petroleum grease, were sent on a sea voyage to the Tropics under conditions of extreme exposure. From the results it is concluded that crude lanoline, which is at present a waste product in the wool industry, provides a rust preventing grease which is a little superior to the best petroleum grease, far superior to a common petroleum grease, and has the additional advantages of being home produced and cheaper in cost.

Wind pressure on bridges. In connexion with the problem of integrating the wind pressures simultaneously existing at a number of points far apart, a form of wind-pressure recorder for electrical connexion with a distant station has been designed and constructed. The instrument is fixed at the roadway level and is operated by a pressure tube carried up above the structure. The pressure tube is connected to a pile of capsule diaphragms which give motion to a brush sliding over a potentiometer wire. A constant current is supplied to the potentiometer wire and the potential drop between the brush and one end of the wire is recorded on a recording voltmeter which may be at any distance. Each instrument is completely insulated, so that the potentials picked off by the brushes of a number of instruments can be added together in series, and the sum will be proportional to the mean pressure at a number of points on the structure.

Causes of failure of wrought iron chains. Heavy static overstraining on new wrought iron chains, with intermediate or final low temperature annealing, entirely fails to produce brittleness. On examining the mechanical properties of chains drawn from service of known history several of these chains were found to be extremely brittle, though no such brittleness could be detected in specimens cut from the interior of the links: a surface effect was clearly indicated. An exhaustive series of repeated impact tests on individual links showed that the core of the link was essentially ductile but was covered by a very thin highly brittle skin. It was then shown that this brittle skin could be produced on new chain links by the application of a large number of small surface impacts which exhausted the ductility of the surface layer, thus rendering the latter liable to crack under comparatively small amounts of tensile strain. The propagation of these cracks from the surface skin to the underlying ductile core is readily accounted for by stress concentration effects at the ends of the cracks and the constraint imposed on the core by reason of its position. It was also shown that removal of the surface layer mechanically, or its recrystallization by means of low temperature annealing, removed the cause of brittleness.

R. T. B.

(*To be continued*)

Collected Researches of the National Physical Laboratory. Vol. XIX, 1926. H.M. Stationery Office. Pp. v + 443. Price 18*s*. 6*d*. net.

The publications of the National Physical Laboratory include the Reports and the Collected Researches. The Reports are a series of small volumes published annually, containing a summary of the work of the preceding year and a forecast of the work of the year to follow. The Collected

Researches, appearing only once every two years, embody a reprint, after revision, of papers representing the work of the Laboratory, which have usually been published already in the Proceedings of learned societies or in scientific magazines. These volumes constitute an impressive record of experimental work, in which the highest skill of the scientist is conjoined with the finished art of the engineer. They take a high place on account of the new technique which they unfold and the accuracy of the experimental results, which are of interest from the purely scientific standpoint, as well as that of industrial application.

The previous volume, published in 1924, was devoted mainly to the work of the Electrical departments. Out of a total of 31 papers in the present volume, 16 relate to measurements in Heat, and 11 to X-rays and Radiology. Four papers deal with thermal conductivity, and it is evident that the Forbes' bar method is practically obsolete, though it continues to occupy a prominent place in the modern text-book. As instances of the scientific interest of the volume may be mentioned the work on the electrical and thermal conductivities of pure metals, and the measurements on crystalline bismuth; whilst amongst the latest applications of scientific research to technology may be cited the use of X-rays in exploring the structure of the crystal lattices of alloys.

D. O.

Comets and the Sun. New Theories Regarding Their Structure. By John W. Weir, M.D., F.R.C.S.E. Pp. xvi + 72, 15 Plates. (London: Longmans, Green and Co., Ltd., 1927.) Price 12*s*. 6*d*. net.

This handsomely-produced volume contains several beautiful illustrations of astronomical phenomena, drawn from various earlier publications. The author writes with respect of the opinions of astronomers, past and present, on the subjects of comets and the sun, and has evidently expended a considerable amount of labour on the analysis of their work and the selection of those portions of it which appear to him to support the theories which he advances. There, however, the merits of the work cease.

Dr Weir's main theory is that a comet is enclosed in a gaseous envelope, against which the interior matter can exert a pressure and from which its radiation can be reflected. The mechanism by which the comet is able to retain this envelope is not explained. The sun also is regarded as possessing a similar envelope, namely, the corona. On the assumption that the planet Saturn had once an envelope surrounding its atmosphere, a process is described by which the rings might have been formed—a process, however, to which physicists are not likely to give their sanction. A theory of the sun is advanced, according to which a considerable portion of the surface of that body is in the solid state.

It is needless to say that the whole substance of the book is quite at variance with orthodox modern thought. This is not in itself necessarily a condemnation, but the author should certainly not preach heresies without considering the reasons which have led the majority of astronomers to radically different conclusions. The evidence which he puts forward for his theories appears to us to be very weak, and has the air more of special pleading than of the inevitableness that envelops a sound theory. There is a naïveté about some of his remarks which can scarcely fail to provoke a smile; for example—"Dark spots in the sun were seen with the unaided eye in China as early as the year 607 B.C. In recent times they have been noticed on several occasions by Mr Maunder." It is a pity that so much time and money should have been spent on a work of so little value to astronomy, and we trust that before taking further steps to publish his views, Dr Weir will give ample and unbiased consideration to observations and deductions which do not accord with his theories.

H. D.

Application of the Algebraic Aberration Equations to Optical Design. By I. C. Gardner. (Scientific Papers of the Bureau of Standards, No. 550.) Pp. 131. (Washington: United States Government Printing Office, 1927.) Price 45 cents.

The purpose of this paper is to provide a guide both to the calculation of the simple heterochromatic and monochromatic aberrations of a given lens system, and to the initial steps in the design of instruments satisfying given aberrational conditions, for students who have only recently made acquaintance with these defects. The author also hopes that his consistency in notation and sign convention may lead to the use of this tract as a reference book.

The formulae given (without proof) relate only to the lowest order aberrations for thin lenses. The general displacements are expressed as angular aberrations in the object space seen from the centre of the entrance pupil. No reason for this preference is stated. The formulae are of the type familiar from the writings of Coddington and Dennis Taylor, but the less symmetrical forms used by Continental workers are also given. The developments of geometrical optics in the last two decades are not mentioned, and in consequence it is not surprising to find that the amount of numerical work involved in the illustrative calculations is excessive. The book also is not free from either typographical errors or inaccurate statements, which must prejudice its suitability as a guide for junior students. Thus it is repeatedly stated that for an object in contact with a thin lens the curvature errors are normal, *i.e.* are $3\phi + P$ and $\phi + P$, where ϕ is the power of the lens and P is the Petzval sum. In reality they are both equal to P, as may easily be seen by considering the image of the curved surface of a lens having the other face plane.

Neither ray tracing nor the significance of the wave-length of the light in estimating the seriousness of residual aberrations is discussed. Details of several deflecting or erecting prisms used in military instruments are given in an appendix. The paper closes with a numerical table of the functions of the refractive index which occur as coefficients in the formulae; with a better choice of variables the greater part of this table becomes unnecessary. T. S.

Dielectric Phenomena. Electrical Discharges in Gases. By S. WHITEHEAD. (Edited with a preface by E. B. WEDMORE.) Pp. 176. (London: Ernest Benn, Ltd.) Price 12*s*. 6*d*. net.

A knowledge of insulating materials is of prime importance in high tension electrical engineering, and a wide field is still open for research. In the past, much experimental work has been carried out in an empirical fashion, and our real knowledge of the subject is consequently somewhat disjointed.

Having regard to the immense importance of the subject in industry, the Electrical Research Association is endeavouring to encourage study of the fundamental phenomena. It is with this object in view that the present volume has been compiled. It consists essentially of a collection of data, much of an empirical nature, summarizing available information which is likely to be of assistance to electrical engineers. The volume is divided into three parts. In the first part a brief outline is given of the ionic theory of conduction in gases generally; in the second "sparkover" is considered; in the third corona, which is regarded as including dark glow, and brush discharges. The main phenomena occurring in electrical discharges through gases at moderately reduced pressures (mean free path small compared with electrode dimensions) form the principal theme of the book. Neither the vacuum discharge nor the arc is dealt with, since in the former the pressures are below the range considered, whilst the latter is not wholly an ionization phenomenon.

The volume contains much useful information which should commend itself to those interested in high tension phenomena. It is unfortunate, however, that the index is so brief (1½ pages containing about 180 references only), for a good index is of vital importance to a work which is intended primarily as a collection of data for reference. A. B. W.

Thermometric Conversion Chart. By PERCY L. MARKS, L.R.I.B.A. (London: Crosby, Lockwood and Son, 7 Stationers' Hall Court, E.C. 4, 1927.) Price 3*s*. 6*d*. net.

A chart is given for the conversion of temperatures between the Absolute scale, the Centigrade, Fahrenheit and Réaumur scales and the little used scale of de l'Isle. From the perfunctory nature of the introductory remarks it would appear that the author is not very closely conversant with the modern science of temperature measurement or with its literature; but the chart should serve a useful purpose. T. M.

CATALOGUES

Messrs Baird and Tatlock (London), Ltd., of 14–15 Cross Street, Hatton Garden, E.C., have recently issued two new catalogues—Technical Research Series, Nos. 2 and 5. The first is devoted to apparatus for the testing of petroleum products, and deals with hydrometers, colorimeters, distillation apparatus, calorimeters, flash-point apparatus, viscometers, and apparatus for deter-

mining water and sediment, saponification and iodine value, demulsification, volatility, dielectric strength, melting points, etc. The second deals with apparatus for the analysis of coal and its by-products, opening with a very useful abstract of the pamphlet on *Methods of Analysis of Coal* issued by H.M. Stationery Office. The list is divided into twelve sections, following the sequence of the procedure above outlined, which makes it very convenient for reference. A useful bibliography and index concludes this well got-up publication.

The 1927 edition of their catalogue of Surveying Instruments, issued by Messrs Cooke, Troughton and Simms, Ltd., is an excellent production. Its four sections deal respectively with Theodolites and Tacheometers; Underground Surveying Instruments; Surveying Levels: and Miscellaneous Surveying Equipment.

The first of these begins with an exceedingly interesting descriptive account of such matters as the accurate division of the circle; the various methods of reading circles, including verniers, estimating microscopes and micrometer microscopes; the importance of telescope design as regards resolution, magnification and light gathering power; diaphragms, stadia lines and numerous other important points. The teacher or student of optics might with advantage study this account as a valuable supplement to the theory of optical instruments. In all some twenty standard pattern theodolites and tacheometers are listed, with excellent illustrations of most types.

In section 2 are shown a number of mining theodolites and mining dials, and in section 3 another excellent series of descriptive specifications of levels, some half dozen standard patterns being illustrated. The fourth miscellaneous section deals with measuring chains, staves, plane tables, barometers, sextants and other appliances.

EIGHTEENTH ANNUAL EXHIBITION OF THE PHYSICAL AND OPTICAL SOCIETIES

THE Eighteenth Annual Exhibition of Electrical, Optical and other Physical Apparatus is to be held by the above Societies on January 10th, 11th and 12th, 1928, at the Imperial College of Science and Technology, South Kensington.

As in previous years, the Exhibition will include the Trade Section, comprising the exhibits of manufacturing firms; and the Research and Experimental Section, initiated in 1926, will again be included. In the latter section the Groups are:

(*a*) Exhibits illustrating the results of recent physical research and improvements in laboratory practice.

(*b*) Effective lecture experiments.

(*c*) Repetitions of historical experiments.

The preliminary invitation to trade exhibitors, giving brief particulars of the arrangements and of the charges, has already been issued and largely responded to. The Exhibition Committee has also invited offers, from Research Laboratories and Institutions and from individual research workers, of suitable exhibits for the Research and Experimental Section. Accommodation for the latter will be provided in rooms separate from those devoted to the trade exhibits; and a part of the Catalogue will be allotted to their description. No charge will be made for space or catalogue entries in this section, and the facilities of the Imperial College will be at the disposal of the exhibitors.

Offers of Exhibits in the Research and Experimental Section, which have been asked for by November 16th, should be sent to the Secretary, Physical and Optical Societies, 1 Lowther Gardens, Exhibition Road, London, S.W. 7. Brief particulars of space and other facilities required should be given.

A new feature of the Exhibition this year will be a morning session on January 11th, for the benefit of members of the Physical and Optical Societies, admission to which will be by special ticket.

As in previous years, a discourse will be given on each of the three days. One of these will be on "Artificial Daylight," by Dr J. W. T. WALSH, another on progress in the recording and reproduction of sound, and the third on modern applications of X-rays and radiology.

DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH

WE are informed by the Secretary of the Department of Scientific and Industrial Research that Sir William James Larke, K.B.E., has been appointed by Order of Council dated the 5th October, 1927, to be a member of the Advisory Council to the Committee of the Privy Council for Scientific and Industrial Research.

JOURNAL OF SCIENTIFIC INSTRUMENTS. BACK NUMBERS

Two shillings per part will be paid for clean, undamaged copies of parts 1, 2, 4, 11 and 12 of Volume 1 of the *Journal*. These should be sent to the SECRETARY, INSTITUTE OF PHYSICS, 1 LOWTHER GARDENS, EXHIBITION ROAD, LONDON, S.W. 7.

TABULAR INFORMATION ON SCIENTIFIC INSTRUMENTS

A FEW sets of the separate tables remain, and may be obtained on application to the SECRETARY, INSTITUTE OF PHYSICS, 1 LOWTHER GARDENS, EXHIBITION ROAD, LONDON, S.W. 7, at a cost of 5*s*. per set. The sets contain eighteen tables, and are complete except for Table II: British Photographic Lenses, which is out of print.

NOTICE TO SCIENTIFIC INSTRUMENT MANUFACTURERS

IN order to keep readers of the *Journal* in touch with the latest developments in scientific instruments, the Editor would be glad if all manufacturers of such instruments would keep him informed of all new instruments or important improvements in their productions as soon as they appear, either by sending him catalogues, pamphlets, or circulars concerning them, or in the case of important developments, by letting him have concise special descriptions of their construction and performance. Descriptions of light machine tools suitable for instrument work would also be appreciated.

LABORATORY AND WORKSHOP NOTES

READERS of the *Journal* are reminded that notes concerning laboratory or test-room methods, and workshop devices or methods of utility to instrument-makers are welcomed, and that ten shillings will be paid for each such note published.

JOURNAL OF SCIENTIFIC INSTRUMENTS

VOL. IV   DECEMBER, 1927   No. 15

TESTING MACHINE FOR GLASS TUBING AND ROD.

By R. F. PROCTOR. Communication from the Staff of the Research Laboratories of the General Electric Company, Ltd., Wembley.

[*MS. received 14th June, 1927.*]

ABSTRACT. An apparatus is described for testing the strength of glass tubing or rod of ordinary dimensions. The maximum strain in the tube at the moment of fracture is used as a criterion of the strength of the glass. A bending moment is applied to the two ends of the specimen, and the breaking strain is derived from a determination of the radius of curvature immediately before fracture. Some results of tests on glass tubes of various diameters are given, and a comparison of tests on annealed and unannealed tubing.

INTRODUCTION

IN the manufacture of glass apparatus one of the important factors is the strength of the glass utilised. If this is considerably below normal, the glass may not be able to withstand the stresses set up by differences of expansion, such as may be caused by unequal heating, joining glasses of different coefficients of expansion, sealing wires into glass, etc. As there is frequently a considerable lapse of time between the production and utilization of glass tubing and rod, several days or even weeks may pass before any information is at hand regarding the strength of the glass drawn. It was thus felt that a simple machine capable of rapidly testing the strength of glass rod and tubing would prove useful to the glass works' staff as an early indication of the quality of the glass being made.

The property first chosen as a criterion of the strength of the glass was the ultimate tensile strength. The specimens, which were short rods, 1 to 5 mm. in diameter, were clamped in the testing machine and a simple tensile stress applied. This method was, however, soon given up owing to the difficulty of clamping the rods satisfactorily. This difficulty was further accentuated by the fact that it was also desired to measure the strength of glass tubing as drawn, *i.e.* without reheating it in any manner. Efforts were then made to measure the tensile strength of the rod and tubing by bending it until it broke. An apparatus was made up whereby the tube was subjected to a uniform bending moment over the test length. The tensile strength was calculated from the bending moment which had to be exerted at the two ends of the tube in order to break it.

This apparatus was found to give reasonably concordant results. However, as the equation used to calculate the tensile strength involved the fourth powers of both the internal and external diameters, this method was not suitable for routine testing, owing to the undue influence of errors in the measurement of the tube dimensions and the amount of work involved in calculating the final result.

To overcome these drawbacks it was decided to calculate the maximum strain in the tube at the time of fracture, instead of its tensile strength, and to modify the apparatus

so as to measure the radius of curvature to which the tube is bent in place of measuring the bending moment exerted. As a result of these alterations it was possible to design a compact portable testing machine the interpretation of whose results involves only the first power of the external diameter of the tubing.

Description of Apparatus

The details of the apparatus are shown in Figs. 1 and 2.

To make a test on a piece of tubing the sample is placed in the apparatus as shown, so that it rests on the fixed pins A, and the handle C is screwed down until the thrust pins B just touch the glass tube. The graduated disc D is then adjusted until the zero coincides with the fixed knife edge E. On slowly screwing the handle C further down, the tube is gradually bent and finally breaks. At the instant the tube breaks the graduated disc is read. The breaking strain may then be calculated from the reading thus obtained

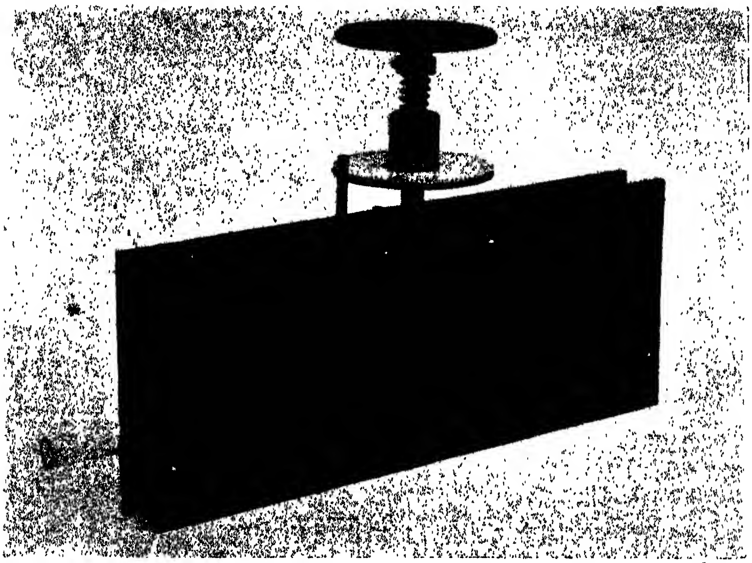


Fig. 1. The testing machine

and the dimensions of the apparatus, by means of equations 1 and 2 (see below). For the apparatus shown in Figs. 1 and 2 ($L_1 = 160$ mm., $L_2 = 40$ mm.) the breaking strain may be determined by means of the following approximate equation, for most of the practical sizes of rod and tubing.

$$\text{Breaking strain} = \frac{x_0 d_0}{7467} \text{ (approx.)},$$

where x_0 = reading on dial in mm. at instant of fracture,

d_0 = external diameter of tube in mm.

In Fig. 2 it is seen that as the handle C is screwed down a bending moment is applied to the tube at each end by means of the two identical pairs of thrust pins A, B. As these are the only bending moments applied (neglecting that due to the weight of the tube) the portion of tube between the pins B will be bent to a constant radius of curvature.

The value of the tensile or compressive strain in any layer of glass is given by the formula

$$\text{strain} = \frac{Y}{R_0},$$

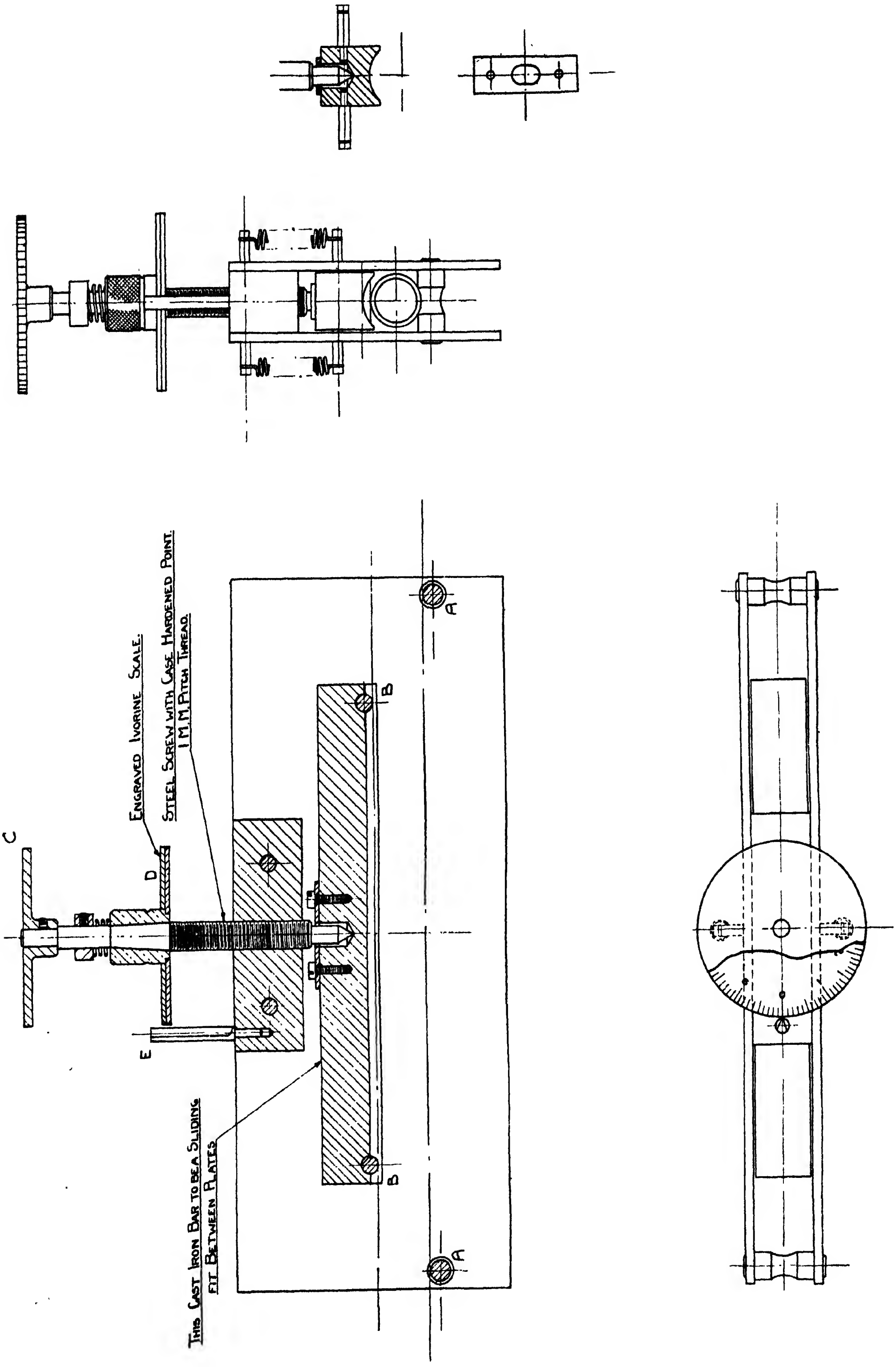


Fig. 2. Glass tube bending test apparatus

where $Y =$ distance of layer from neutral axis,

$R_0 =$ radius of curvature to which the tube is bent.

The strain reaches a maximum when Y is equal to the external radius $\frac{d_0}{2}$, whence

$$\text{Maximum strain in tube} = \frac{d_0}{2R_0} \qquad \text{......(1).}$$

From the nature of the case it is readily seen that the value of this maximum is independent of the internal diameter of the tube.

The radius of curvature R_0 may be evaluated approximately in terms of the distance moved by the thrust pins B and the dimensions of the apparatus as follows (see Fig. 3),

$$\frac{d^2x}{dz^2} = \frac{1}{R} = \frac{M}{EI},$$

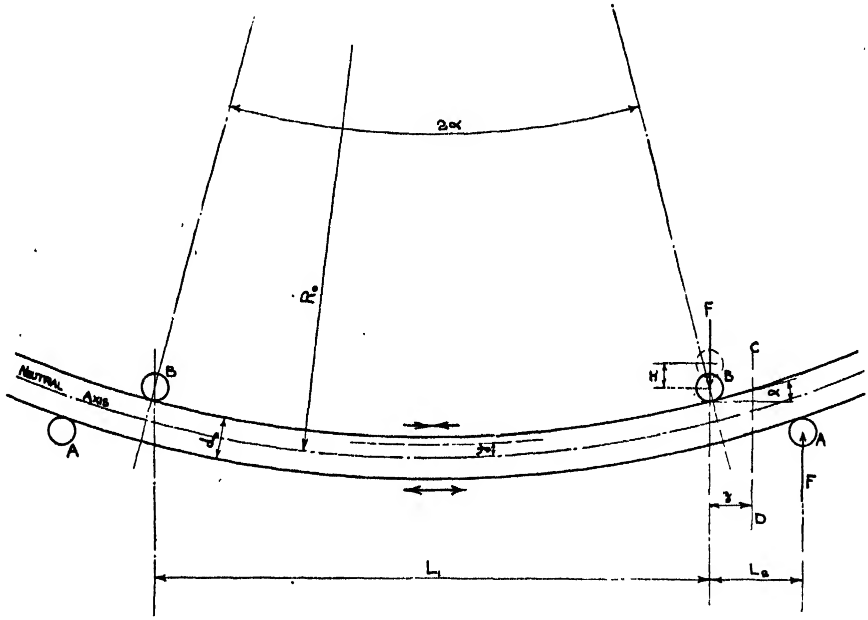


Fig. 3. Diagram of glass tube bending apparatus

where $E =$ Young's Modulus,

$I =$ Moment of inertia of cross section,

$M =$ Bending moment at section C, D,

$R =$ Radius of curvature at section C, D.

Bending moment "M" at section $C, D = F(L_2 - z)$.

Hence
$$\frac{d^2x}{dz^2} = \frac{FL_2}{EI} - \frac{Fz}{EI}.$$

Integrating the above differential equation between the limits $z = 0$ and $z = AB$ we obtain

Distance "x_0" moved by thrust pins $B = \dfrac{FL_2^3}{3EI} + L_2 \tan\alpha = \dfrac{FL_2^3}{3EI} + \dfrac{L_1L_2}{2\sqrt{R_0^2 - \dfrac{L_1^2}{4}}}.$

But
$$\frac{FL_2}{EI} = \frac{1}{R_0}.$$

Hence
$$x_0 = \frac{L_2^2}{3R_0} + \frac{L_1 L_2}{2\sqrt{R_0^2 - \frac{L_1^2}{4}}} \quad \text{......(2).}$$

For the apparatus shown in Figs. 1 and 2

$$L_1 = 160 \text{ mm.},$$
$$L_2 = 40 \text{ mm.},$$

whence
$$x_0 = \frac{533{\cdot}3}{R_0} + \frac{6400}{2\sqrt{R_0^2 - 6400}}.$$

Since R_0^2 is large compared with 6400 for most of the practical sizes of rod and tubing, the 6400 term under the square root may be neglected without introducing any appreciable error, and the equation reduces to

$$x_0 = \frac{3733{\cdot}3}{R_0}.$$

By combining this equation with equation 1, we obtain

$$\text{Breaking strain} = \frac{x_0 d_0}{7467} \text{ (approx.).}$$

Results

A typical series of measurements on unannealed (see below) glass tubes of various diameters and wall thicknesses is given in Table I, and clearly illustrate that the breaking strain is practically independent of the tube dimensions.

To determine the effect of annealing on the breaking strain results, 25 pieces of tubing were taken and each cut into four pieces. Two of each of these were taken and annealed before testing, whilst the other two pieces were tested in their unannealed state.

Table I

Diameter in mm.	Wall in mm.	Breaking strain $\times 10^{-3}$				Mean breaking strain $\times 10^{-3}$
2·8	0·35–0·45	0·71	0·98	1·03	0·70	1·05
2·7	,,	1·03	0·98	1·10	1·00	
3·0	,,	1·60	1·10	1·18	1·04	
3·0	,,	0·93	1·11	1·08	1·22	
3·5	0·6	1·08	1·18	1·12	1·02	1·11
3·5	0·7	1·05	1·25	1·11	0·87	
3·5	0·7	0·92	1·32	0·86	1·25	
3·8	0·7	0·99	1·58	1·46	0·72	
8·4	0·8	1·08	0·90	1·07	—	1·09
8·7	0·8	1·22	1·05	1·39	1·16	
8·0	0·7	1·23	1·01	1·01	1·11	
8·2	0·9	1·09	0·93	1·11	1·00	
11·7	1·1	0·99	1·11	1·09	0·98	1·05
11·5	1·0	0·95	1·01	0·91	1·04	
11·0	0·9	1·17	1·09	1·05	0·79	
11·0	0·9	1·03	1·20	0·94	1·50	
14·0	1·4	1·30	1·24	1·15	0·95	1·29
14·0	1·2	1·39	1·04	1·15	1·30	
14·0	1·2	1·52	0·99	1·16	1·49	
14·0	1·3	1·71	1·65	1·61	1·14	
3·5	Rod	1·22	1·10	1·15	1·31	1·24
4·0	,,	1·21	1·39	1·44	1·31	
3·8	,,	0·94	1·29	1·41	1·39	
4·0	,,	1·29	0·95	1·35	1·12	

The mean values obtained for the two series of 50 breaks were

Unannealed $0{\cdot}97 \times 10^{-3}$.
Annealed $0{\cdot}96 \times 10^{-3}$.

Also the "amount of spread" of the individual readings from the mean was found to be approximately the same in both cases.

From these results it would appear that the degree of strain usually present in glass tubing as drawn is not sufficient to cause any appreciable errors in the determination of the breaking strain.

NOTE ON ANEMOMETER THEORY. By E. OWER, B.Sc., A.C.G.I., and W. J. DUNCAN, B.Sc., A.M.I.Mech.E.

[*MS. received, 29th July*, 1927.]

ABSTRACT. A new method of correcting the readings of a vane anemometer for changes of air density is shown; and some experiments are described for the determination of the force coefficient K for anemometer blades.

Correction for Changes of Air Density. In an earlier communication* by one of the authors a method of successive approximation was proposed for correcting the readings of a vane anemometer for variations of air density. Since the publication of that note the theory of the anemometer has been further developed, and a simpler method of making allowance for changes of density has been found.

For convenience, the following brief recapitulation is given of the portions of the previous note which are essential to the present discussion. In Fig. 1, which is reproduced from that note, AB represents one of the blades of the anemometer inclined at an angle θ to the wind direction, and O is the centre of pressure of the blade. Under the action of the wind, AB moves instantaneously along OP, perpendicular to the wind direction QO, with a velocity v such that the resultant of v and the wind speed V, *i.e.* the wind speed relative to the blade, is V_r, and is inclined at an angle ϕ to the plane of the blade. The resultant aerodynamic force on the blade will act along OT, which makes an angle γ with OS, the normal to the relative wind direction. Under these circumstances it was shown in the original note that the aerodynamic torque F on all the blades of the anemometer could be written in the form

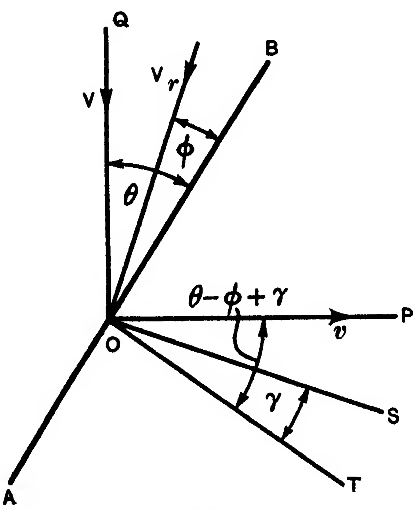


Fig. 1

$$F = K\phi\rho A\,(V^2 + v^2)\,nr\cos(\theta - \phi + \gamma), \qquad \ldots\ldots(1)$$

where K is a coefficient depending on the incidence ϕ,
ρ is the density of the air (mass per unit volume),
A is the area of one blade,
n is the number of blades,
and r is the distance of the centre of pressure O from the axis of rotation.

* "A Low Speed Vane Anemometer." By E. Ower, *Journ. Scient. Instr.* **3** (1926) 109. See also "The Theory of the Vane Anemometer," by E. Ower, *Phil. Mag.* (1926, II) 881.

Now when the anemometer blades are rotating uniformly in a steady wind, the aerodynamic torque F will be numerically equal to the mechanical torque T resisting the motion. The mechanical torque is made up of two components, one due to the weight W of the moving parts, and one due to the end thrust of the spindle on the rear bearing, arising from the component N of the resultant wind force in the direction of the axis of the instrument. Hence we may write

$$T = \mu W r_1 + \mu N r_2 \qquad \text{......(2)}$$

where μ is the coefficient of friction, and r_1 and r_2 are the effective radii at which the forces μW and μN act.

If, as is generally the case, the bearings are cylindrical it is justifiable to regard r_1 and r_2 as constant. If, further, we assume that μ is constant*, we may, since W is constant, write (2) in the form

$$T = g + hN \qquad \text{......(3)}$$

where g and h are constants.

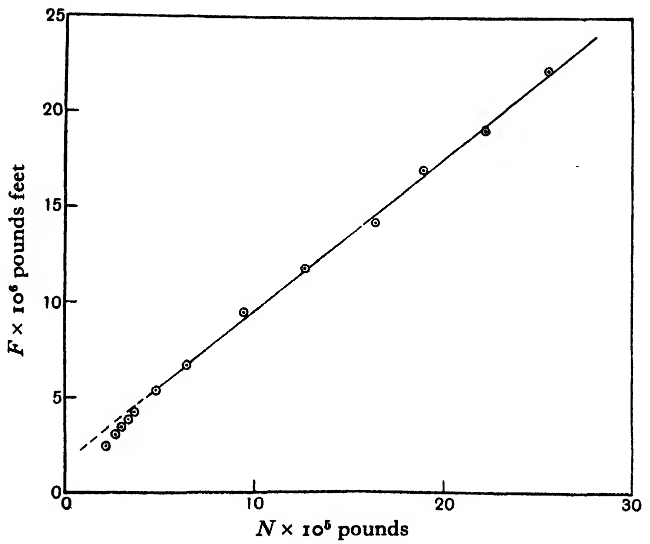


Fig. 2

The torque T, being equal to F, can be calculated from (1) in the manner previously described. The thrust N is given by the similar equation

$$N = K\phi\rho A\,(V^2 + v^2)\,n \sin(\theta - \phi + \gamma) \qquad \text{......(4)}$$

and is calculable in an analogous manner.

From (3) we may expect the graph of T against N, that is, of F against N, to be a straight line. Values of these quantities for the low speed anemometer described in the earlier note have been calculated† and are plotted in Fig. 2. It will be seen that, except for the small values near the origin—corresponding to wind speeds below 1 ft per sec.—the points lie well on a straight line, and thus supply confirmation of the above reasoning. The departure from linearity at low speeds may be due to a variety of causes, one of which is a possible change in μ at these very slow relative speeds of the journals and their bearings. This matter will not be discussed here in any detail: it is thought that the method of density correction

* See later.

† The calculations are based on the results of measurements of wind forces on anemometer blades. See below.

developed below, which depends on a linear relation between F and N, will give sufficiently accurate results even at the very low speeds where this relation does not hold rigidly.

Suppose the anemometer to have been calibrated in air of density ρ_0. Let F_0 and N_0 correspond to a wind speed V_0 for which the blade speed is v_0. Now suppose the air density changes to ρ_1; at a certain wind speed V_1, corresponding to a blade speed v_1, the value of F will be the same as before, that is

$$F_0 = g + hN_0 = F_1 = g + hN_1$$

from which it follows that $N_1 = N_0$. Hence

$$K_0\phi_0\rho_0 A\,(V_0^2 + v_0^2)\,nr\cos(\theta - \phi_0 + \gamma_0) = K_1\phi_1\rho_1 A\,(V_1^2 + v_1^2)\,nr\cos(\theta - \phi_1 + \gamma_1) \quad \ldots\ldots(5)$$

and

$$K_0\phi_0\rho_0 A\,(V_0^2 + v_0^2)\,n\sin(\theta - \phi_0 + \gamma_0) = K_1\phi_1\rho_1 A\,(V_1^2 + v_1^2)\,n\sin(\theta - \phi_1 + \gamma_1) \quad \ldots\ldots(6)$$

Dividing (6) by (5) we obtain

$$\phi_0 - \gamma_0 = \phi_1 - \gamma_1$$

and since γ is a definite function of ϕ, it follows that

$$\phi_0 = \phi_1.$$

Now it was shown in the previous note that $\frac{v}{V} = \tan(\theta - \phi)$. Hence, by virtue of the equality of ϕ_0 and ϕ_1, we must have

$$\frac{v_0}{V_0} = \frac{v_1}{V_1}. \quad \ldots\ldots(7)$$

Also, since K is a function of ϕ, $K_0 = K_1$. Equation (5) therefore reduces to

$$\rho_0\,(V_0^2 + v_0^2) = \rho_1\,(V_1^2 + v_1^2),$$

and, combining this with (7), we establish the relations

$$\frac{v_1}{v_0} = \frac{V_1}{V_0} = \sqrt{\frac{\rho_0}{\rho_1}}. \quad \ldots\ldots(8)^*$$

A ready means of deriving the calibration curve of an anemometer at density ρ_1 from that at density ρ_0 is thus indicated, since, from (8), a point (v_0, V_0) on the ρ_0 curve becomes the point $\left(v_0\sqrt{\frac{\rho_0}{\rho_1}},\ V_0\sqrt{\frac{\rho_0}{\rho_1}}\right)$ on the ρ_1 curve. The new calibration curve is thus always geometrically similar to the old one. If the original is a straight line of equation

$$v = pV + q,$$

the new graph will be the parallel straight line

$$v = pV + q\sqrt{\frac{\rho_0}{\rho_1}}.$$

It should be noted that if $q = 0$, the new line coincides with the old, and provided q is small the distance between the lines will be small.

In practice it is not necessary to draw a new calibration curve each time the value of ρ changes. The air speed corresponding to an observed blade speed when the density is ρ_1 can be obtained from the ρ_0 curve by calculation as follows: The observed blade speed v is multiplied by the ratio $\sqrt{\frac{\rho_1}{\rho_0}}$ to give the corresponding blade speed at density ρ_0. The value of the wind speed V corresponding to this blade speed $v\sqrt{\frac{\rho_1}{\rho_0}}$ is then read off the

* This equation can also be readily deduced by dimensional theory.

calibration (ρ_0) curve, and the required value of V is then equal to $V\sqrt{\frac{\rho_0}{\rho_1}}$. It is of course not necessary actually to calculate the blade speed v; the correction can be applied in exactly the same manner, using the rotational speed of the pointer of the instrument in place of the blade speed.

It may be well to point out that Table I of the former note gives the calculated percentage change of blade speed corresponding to a 3 per cent. change of air density, and that the corresponding percentage errors of the air speeds as read from the calibration curve are

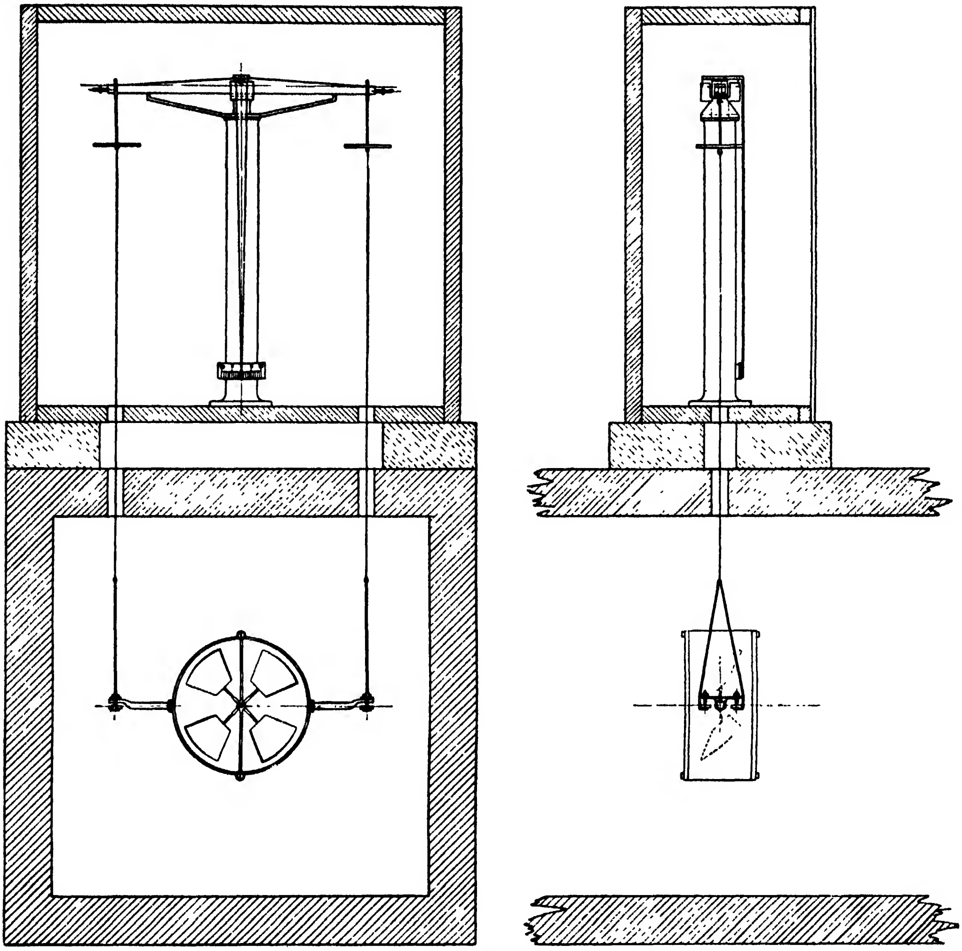


Fig. 3

much less. As a general rule, unless the highest possible accuracy is needed, the effect of variations of density not exceeding 5 per cent. can be neglected.

Values of the Force Coefficient K. The only data hitherto available for the calculation of K for anemometer blades were those obtained by G. Eiffel on square plates. Eiffel's experiments were made with plates set in a free air stream, the smallest plate used being 25 cm. square. It will be realised therefore that the conditions to which these results apply differ considerably from those under which the blades of an anemometer work, and it was thought desirable to measure, if possible, the actual forces acting on anemometer blades.

The work was carried out in a small wind tunnel at the National Physical Laboratory. A four-bladed anemometer whose blade angles could be varied was employed for the purpose. The general arrangement of the apparatus is shown in Fig. 3. A small chemical

balance was mounted on the roof of the tunnel, the scale pans being replaced by two stirrups slung from wires passing through the tunnel roof. Each stirrup carried two horizontal plane surfaces of polished, hardened steel, arranged to lie mid-way between the roof and floor of the tunnel. Two arms were attached to the anemometer casing, on the horizontal diameter of the instrument, and each arm carried, at a radius equal to half the total length of the balance arm, a pair of hard steel points which rested on the plane surfaces of the stirrups. Any wind torque acting on the anemometer produced a deflection of the balance, which could be restored to its zero position by adding weight to one of the small scale pans shown in the sketch. The torque could easily be calculated from a knowledge of the leverages and the amount of weight added.

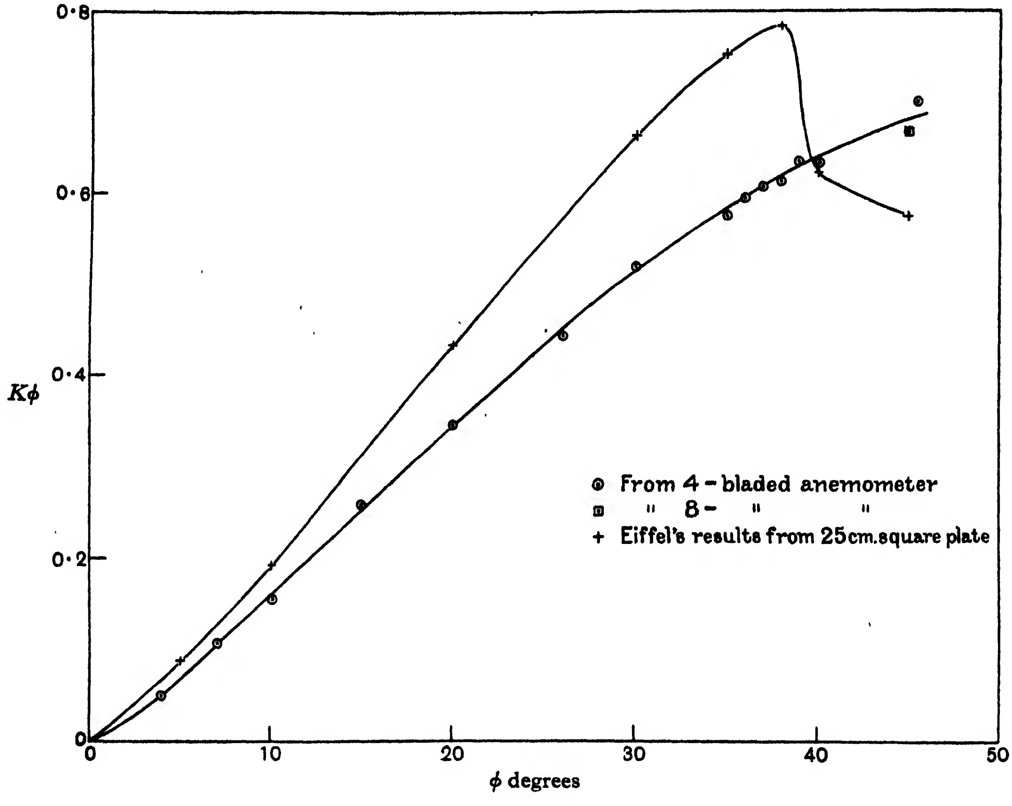


Fig. 4

In an experiment the blades were first carefully set at a known angle to the axis of rotation, which coincided with the wind direction. They were then clipped to the frame to prevent rotation, and the balance was adjusted to its zero position. A series of readings of the torque was then taken over a range of wind speeds. Sets of measurements were made at angles of incidence varying from 4° to 45°, and readings were also made with the blades removed in order to correct for any small torque that might arise from an asymmetry of the anemometer casing or of the method of support.

From the measured torque the value of K could be calculated by the use of equation (1), on the assumption that γ was equal to ϕ, that is, that $(\theta - \phi + \gamma) = \theta$. This assumption, which is equivalent to the hypothesis that the resultant force acts normally to the blade, is supported by practically all the existing data relating to flat plates and aerofoils of conventional design, and is in all probability sufficiently accurate except possibly at angles of incidence less than 2°. Further, it should be noted that at small incidences, where γ may

differ appreciably from ϕ, the angle $(\theta - \phi + \gamma)$ will be small and the rate of change of its cosine will also be small. It will, then, be clear that, since (1) involves $\cos(\theta - \phi + \gamma)$, γ may differ from ϕ by as much as 10° when $\theta = 1°$ without causing an error of 2 per cent. in K. Hence it is highly improbable that the values of K as calculated on the assumption that $\phi = \gamma$ can be appreciably in error, even at the lowest angle of incidence—4°—covered by these tests. The results are shown in Fig. 4, in which the quantity $K\phi$ is plotted against ϕ, the angle of incidence. Eiffel's results are plotted on the same diagram, and it will be seen that whilst the curves are of similar shape, the values for the anemometer blades are consistently lower than those relating to the larger square plates of Eiffel, except near the "stalling angle" where the flow round the plate is liable to change rapidly.

The anemometer used for these experiments was sufficiently representative of the usual design of such instruments for the results obtained to have a general application. A check point, shown on the diagram, was obtained from a similar experiment with the low speed anemometer previously mentioned, which had eight blades, and the agreement is seen to be good, particularly when it is remembered that this instrument had a much closer blade spacing than that used for the other experiments. Only one point—at 45° incidence—was obtained with the low speed anemometer since this was a standard instrument whose blade angles could not be altered.

THE MEASUREMENT OF MOISTURE MOVEMENTS IN BUILDING MATERIALS.

By F. L. BARROW, M.Sc., of the Building Research Station.

[*MS. received, 2nd June*, 1927.]

ABSTRACT. The paper deals with two forms of apparatus in use at the Building Research Station for measurement of the expansion of building materials under the influence of moisture. The two forms of extensometer used to magnify the displacements of the specimen are described in detail. The movements may be recorded autographically; and the apparatus may be adapted for measurements due to changing humidity of the air or on immersion in water.

THE instruments now in use at the Building Research Station for measuring the expansion and contraction of building materials under varying moisture conditions are mechanical in principle and consist essentially of a lever mechanism, with an optical arm, to magnify the actual movement of the specimen. The general arrangement of the apparatus is as follows:

The specimen, which may be of any dimensions up to 3 in. square and 6 in. high, is placed upon a rigid base. Immediately above the specimen is suspended the rocking arm, which is connected *below* to the top of the specimen and *above* to the calibration unit. By this method of suspension the rocking piece may be actuated either by the movement of the specimen or by rotation of the micrometer calibrating screw; thus a correct ratio between scale divisions and true linear movements may be determined immediately prior to a test with the specimen in position.

Details of design of these extensometers may be seen from the drawings and photographs (Figs. 1 to 7). Two types of instrument are in use, differing chiefly in the rocking piece and in the method of its suspension. In both types of apparatus the supporting framework is the same and consists of a heavy metal base, vertical rods running up on either side of the specimen to carry the micrometer cross bar and a moving head (working in a guide and connected to the rocking piece) which may be raised and lowered by means of the micrometer screw.

The rocking pieces themselves require rather more detailed description. The knife-edge type of rocking piece (Figs. 1, 2 and 3) is simply a single lever suspended at two points from

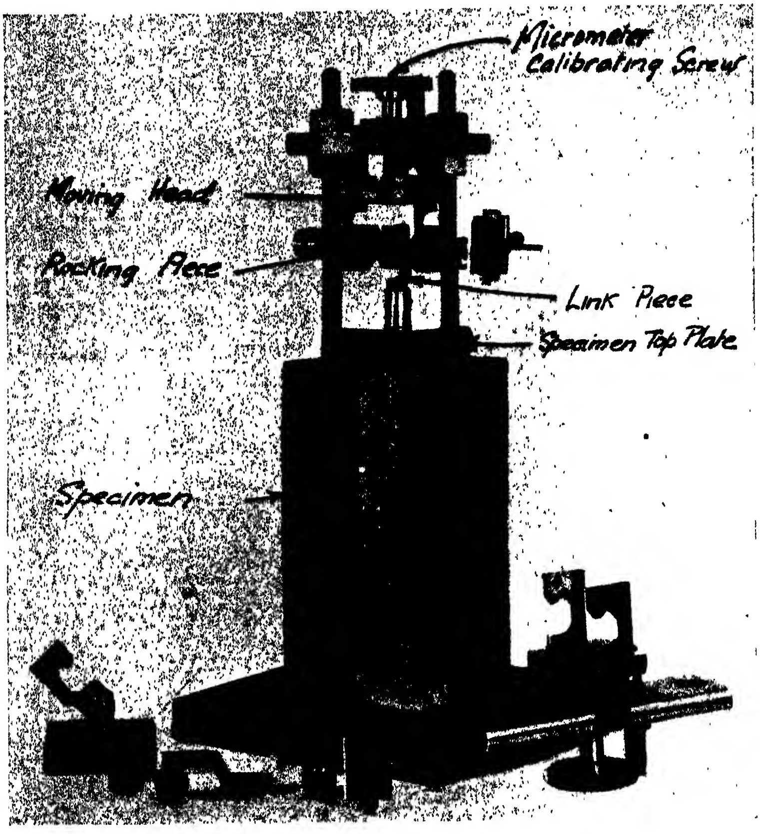


Fig. 1 Extensometer, Type I. Apparatus assembled, also shewing Components

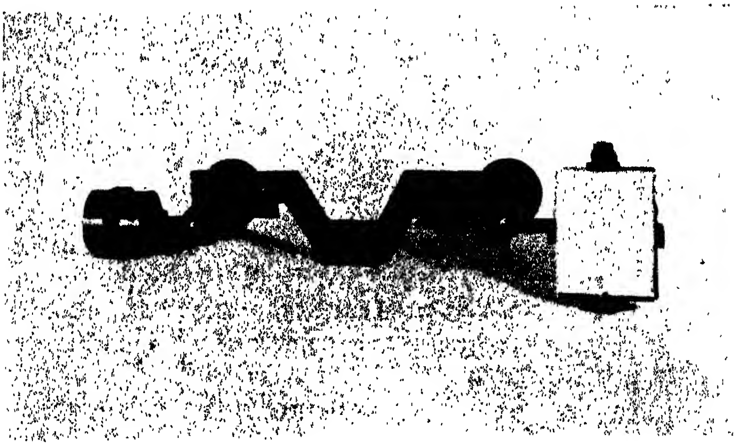


Fig. 2. Extensometer, Type I. Knife-edge Rocking Piece

the moving head and rocked at a third point by a link from the specimen top plate, making contact a short distance away from the fulcrum. Balance weights are attached to the rocking piece in such a manner that a small tension is required in this link. Attachment of a mirror

parallel to the axis of suspension provides an "optical arm" to this lever of any required length up to 20 ft. and readings may be made with this mirror by the usual methods of

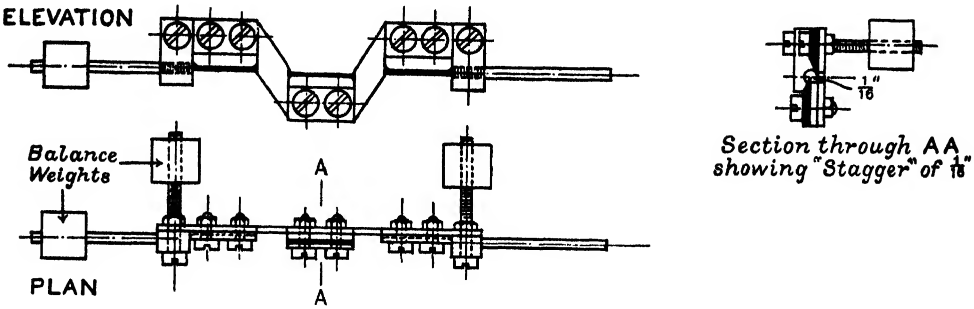


Fig. 3. Extensometer, Type I. Detail of Knife-edge Rocking Piece

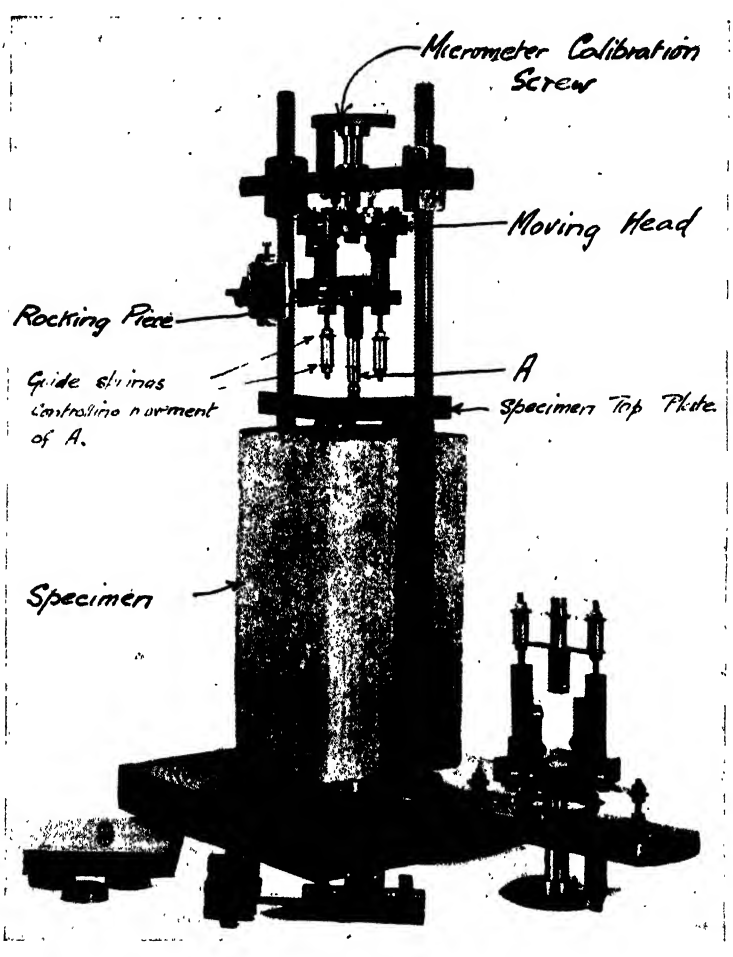


Fig. 4. Extensometer, Type II. Apparatus assembled, also showing Components

telescope and scale or by reflection of a beam of light. A very high degree of magnification is obtained by making the short arm of the lever $\frac{1}{16}$ in. or less. The practical difficulties of constructing a satisfactory lever with so small a distance from fulcrum to actuating point

are overcome by supporting, as shown, at two points some distance apart and arranging that the link makes contact *between* them but not exactly in the same plane, a stagger of $\frac{1}{16}$ in. (or less) being allowed. This arrangement is made clear in the detail of rocking piece in Fig. 3, where the rocking piece is seen to consist of three knife edges so attached to a backing plate that the inner edge is "staggered" $\frac{1}{16}$ in. from the outer edges. The outer edges, pointing downwards, fit in the crossed knife-edge sockets attached by brackets to the moving head; the centre edge, pointing upwards, is held in a similar socket which forms the upper end of the link to the specimen. This link is hinged at its lower end to the specimen top plate to allow the necessary lateral freedom as the lever undergoes small rotations.

The rocking piece is brought to the working position approximately by nuts on the side rods and finally by the micrometer screw. The dial of the micrometer screw is graduated in main divisions of 0·001 in. and subdivided to 0·0001 in. An average value obtained in calibration is 4 in. on the scale to 0·001 in. actual movement, representing a magnification of 4000 times.

The second type of rocking device is shown in Figs. 4, 5 and 7. Knife-edge pivots are here replaced by "hinges" of steel ribbon. This modification was made to ensure greater

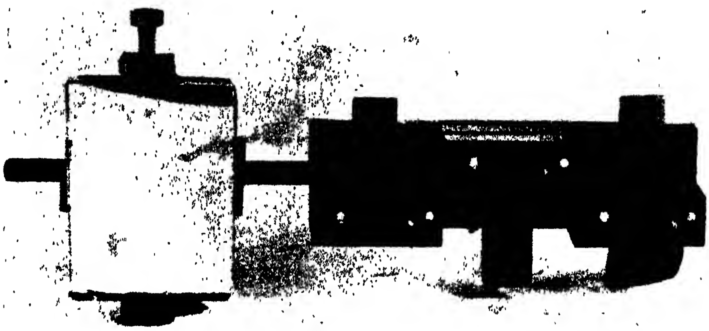


Fig. 5. Extensometer, Type II. Rocking Piece carrying Steel Strips

stability under accidental vibrations, to avoid the wear of fine steel edges and to preserve a constant calibration ratio for a given scale distance.

The action of such a flexible "hinge" is illustrated in the sketch in Fig. 6. A represents the top plate of the specimen and B the moving head. They are shown connected by steel ribbon fixed to opposite sides of a rod R. Elongation of the specimen produces a bending of the strips as shown in the second figure and imparts a rotation to R and to the mirror M which it carries.

In the actual instrument the "stagger" principle is again employed in constructing the rocking piece (see Fig. 7) to reduce the effective width of R; modifications are also made to bring the clamping points on to the same horizontal plane. (See also Fig. 5.)

Other details in design are illustrated in Fig. 4. The provision of short metal cylinders, domed at one end and plane at the other, serving as three point contacts between the specimen and its end plates, ensures stability of the specimen under test even when the end surfaces are somewhat irregular and thus renders accurate facing unnecessary. These "feet," and also the surfaces of top and bottom plates, are made of stainless metal as they may have to remain immersed in water for long periods. The vertical rods are screwed along their whole length, to accommodate specimens of any length up to 6 in.

Movement of the specimen during test is transmitted to the rocking piece through a short vertical rod (A in Fig. 4) held by two flat springs (connected by end supports to the moving

head) which allow it limited vertical movement while preventing lateral displacement or inclination from the perpendicular. The actual contact between the lower end of this rod and the specimen top plate is made through a $\frac{1}{4}$ in. diameter steel ball. In this way any

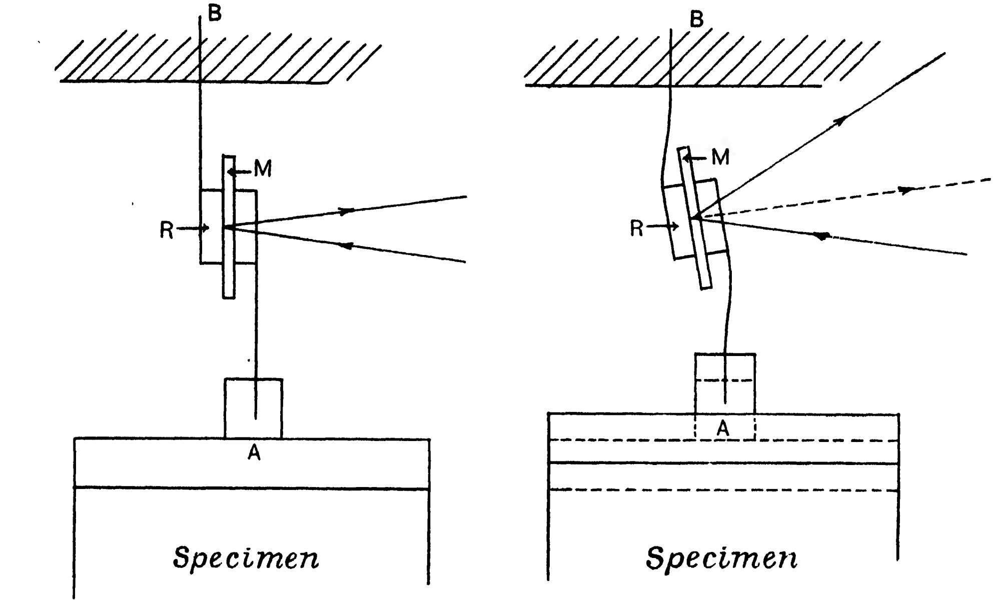


Fig. 6. Diagram illustrating the Action of a Rocking Arm supported on Flexible "Hinges" of Steel Ribbon

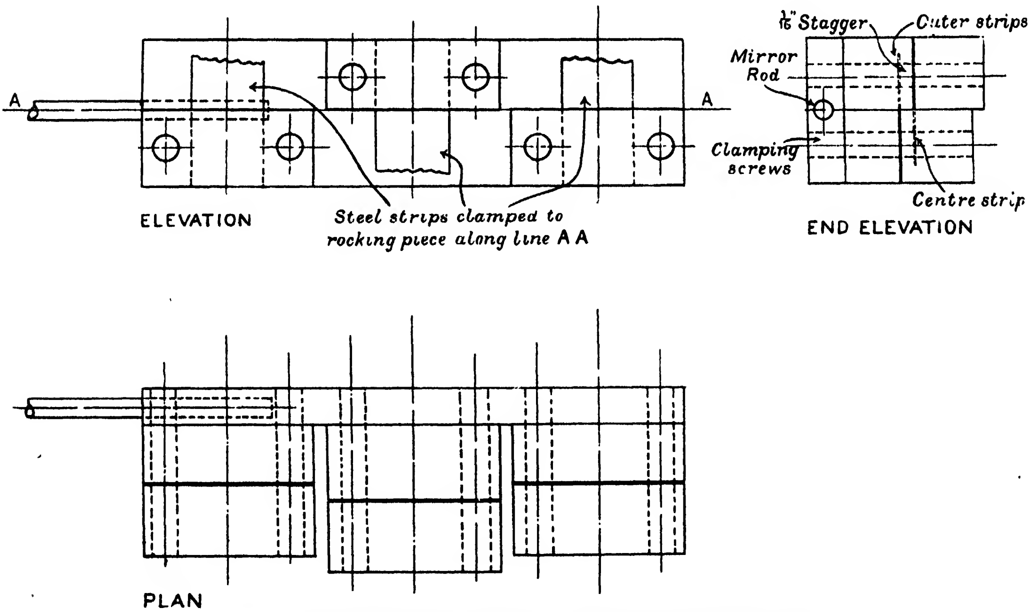


Fig. 7. Extensometer, Type II. Detail of Rocking Piece

slight movements of the specimen other than those of vertical translation will not affect the recording mechanism and no restraint can be applied from the one to the other.

These instruments may be used to record length changes with changing humidity of surrounding air or on immersion in water. The former are conducted by enclosing the instrument in a chamber of air whose relative humidity can be controlled, the latter by

surrounding the specimen by a tube of about 5 in. diameter and a little higher than the specimen, clamped down to the base plate on a rubber washer; into the tank so formed water may be introduced to immerse the specimen.

Movements are recorded autographically when required by projecting a ray of light on to the mirror of the extensometer and thence on to sensitised paper attached to a rotating drum. The projector throws a horizontal slit of light on to the mirror of the instrument. The reflected ray is directed against the face of the recorder which carries a narrow *vertical* slit, thus allowing only a sharp point of light to reach the sensitised paper. Movement of the specimen rotates the mirror through a small angle and causes the spot of light to travel vertically over the paper; at the same time the drum, driven by clockwork, carries the paper horizontally past the slit. A curve is thus traced out showing magnified movement against time. The slit from one projector may be arranged, if required, to span the mirrors of several extensometers, reflecting to corresponding recorders. Calibration when recording autographically is effected by comparing movements of the micrometer head with movements of the horizontal slit over a scale pasted on the face of the recorder.

Both types of rocking device used in these extensometers have also been adapted for use in strain gauges.

AN AUTOMATIC HUMIDITY CONTROL. By

W. H. APTHORPE, A.M.I.E.E. (Cambridge Instrument Co., Ltd.) AND J. J. HEDGES, PH.D., F.INST.P. (British Research Association for the Woollen and Worsted Industries).

[*MS. received 6th October*, 1927.]

ABSTRACT. It is often necessary to maintain constant atmospheric humidity in rooms where hygroscopic substances such as textile materials, tobacco, paper, etc., are being tested or stored, or for the seasoning of timber and the preservation of foodstuffs.

The control described in this paper is based on the principle of the ordinary hair hygrometer, and has been designed to operate electrical relays which govern the supply of dry or moist air necessary to preserve constant humidity in an enclosure.

DESCRIPTION OF CONTROL

THE general arrangement of the instrument is shown in Fig. 1. A single horsehair H, 40 cm. in length, is fixed at one end to a base D, while the other end is attached to the spring C which is provided with an adjusting screw E whereby the tension of the hair may be varied. To the midpoint of the hair is attached a thin metal strip G which passes round a pulley fixed to the spindle F; this spindle also carries a pointer. The length of the hair varies with the humidity of the surrounding air, causing variations in the amount of sag, resulting in corresponding movements of the pointer. Torsional control of the spindle is effected by means of two spiral springs K_1, K_2, which are insulated from the spindle; from these springs connections are made by means of fine wires to the ends of a differential thermo-couple A, B formed of copper-constantan elements, which is mounted at the extreme end of the pointer, and to a moving coil relay. (This device has been used with considerable success in an automatic temperature regulator. See British Patent No. 194597.) Mounted immediately above the junctions of the thermo-couple is a small electrically heated coil L which is maintained at a dull red heat by a current of 0·6 ampere from a 2 volt accumulator.

From the apparatus described, connections are made to two relays which control the supplies of moist and dry air to the chamber. These relays are marked *M* and *N* in the diagram (Fig. 2). When the pointer is mid-way between the thermo-couples, both junctions are equidistant from the heater, the moving coil relay is in its zero position and neither of the relays *M* and *N* are energised. If the air becomes drier, the hair will shorten, causing the pointer to move so that junction *B* is close to the heater. The moving coil relay will then be deflected, thus energising the relay *M* which controls the supply of moist air. When the air becomes too moist, the hair will lengthen causing junction *A* to be influenced by the heater, thus energising relay *N* which controls the supply of dry air.

The adjustment of the control to give the required humidity is performed by trial and error in conjunction with a standard hygrometer. This is done by turning the screw *E* until

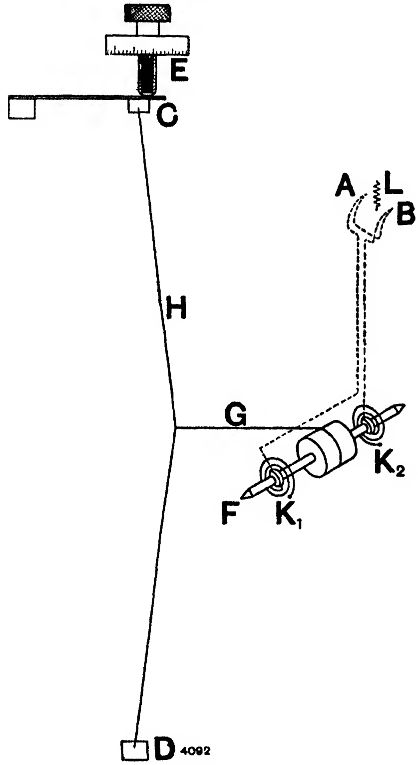


Fig. 1

the pointer is in the centre position when the humidity is at the required value. The time taken to do this, will, of course, depend on the rate at which the air is being circulated; under the conditions described below, the instrument could be reset to control at any desired humidity by occasional attention during the space of two hours.

The hair, which is specially selected and treated to remove any trace of grease, is enclosed in a perforated metal cylinder which allows free air circulation around the hair but protects it from accidental damage. The spindle carrying the pointer, thermo-couple, etc. is enclosed in a sealed case, marked *P* in Fig. 3. The complete outfit is illustrated in this figure.

Description of Test

The control has been used to govern the constant humidity room of the British Research Association for the Woollen and Worsted Industries for several months, and has proved very reliable. The room has a capacity of 1700 cubic feet and the air is completely changed

in rather less than half an hour. The air so removed is either passed over calcium chloride or wet pumice, or is untreated, and then passes back into the room. The treatment received by the air depends on the opening and closing of valves by means of electromagnets operated by the relays controlled by the apparatus under description. A table is given below showing the results obtained when the room was maintained at approximately 80, 70, 60 and 55 per cent. relative humidity. The humidity values were obtained from readings taken at 9 a.m. each day (Sundays excluded) on a wet and dry bulb hygrometer situated in the centre

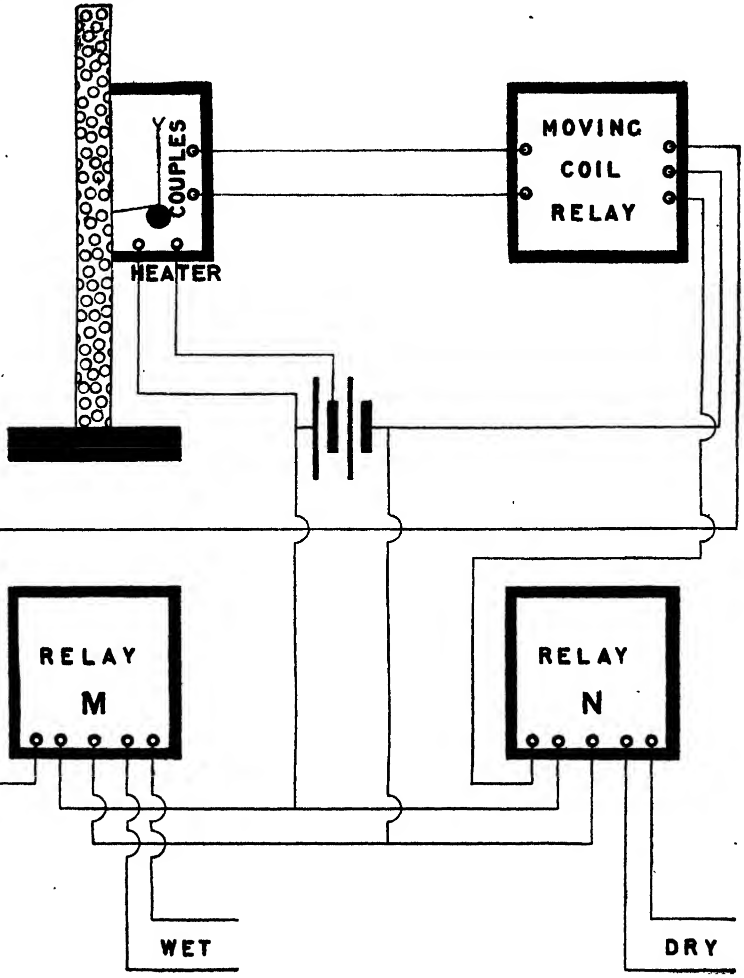


Fig. 2

of the room. Measurements were also made from time to time as a check, in accordance with the usual routine of the constant humidity room, with an Assman hygrometer, by the dew-point method, and by the glycerine refractive index method.

RESULTS OF TEST

Period of test inclusive	Aver. humidity for period %	Highest daily value %	Lowest daily value %
March 26th–June 3rd	70·2	71·6	69·0
June 8th–June 13th	79·8	80·0	79·0
June 21st–July 5th	70·7	71·8	69·8
July 16th–July 22nd	59·6	60·6	59·0
Aug. 5th–Aug. 13th	55·3	56·2	54·0

Temperature 70° F.

The days in between the above periods do not represent time taken to re-set the instrument but were holiday periods or time taken to renew the calcium chloride, together with a day or two for steady conditions to be reached.

During the period of ten weeks in which the average humidity was 70·2 per cent., the highest daily value of 71·6 per cent. was only reached twice and the next highest value of 71·4 per cent. was also only reached twice. A daily reading of 69·8 per cent. was obtained ten times. The mean deviation during the whole period was 0·95 per cent. It must

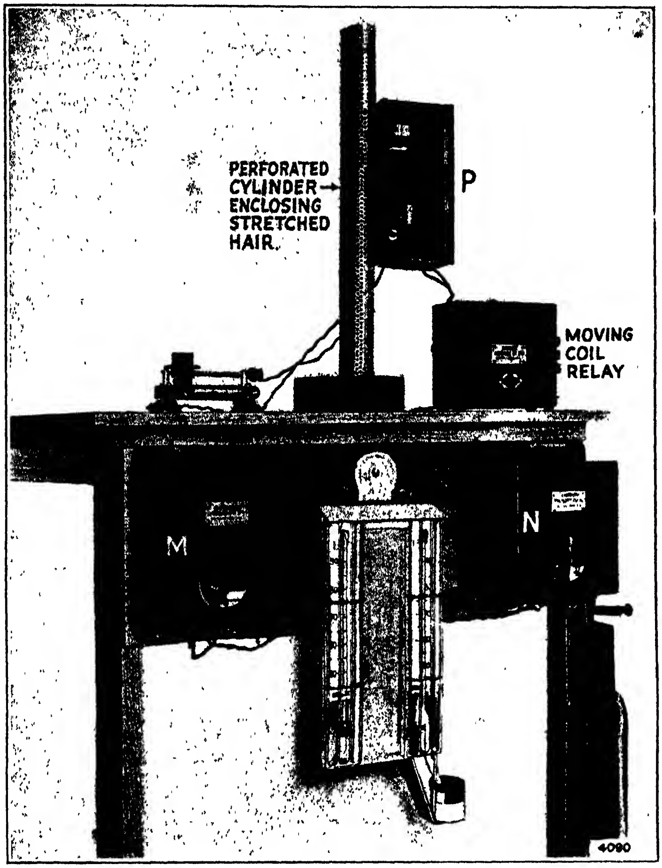


Fig. 3

be pointed out that small errors in reading the thermometers of the wet and dry bulb hygrometer would account for a large portion of the difference from the mean of the extreme values of the relative humidity.

The instrument has not been tested at humidities lower than 55 per cent., but since the rate of change in length of a hair with change in humidity is greater at lower humidities the instrument would then be even more sensitive. Temperature also influences the length of the hair, but since it is usual to maintain constant humidity rooms also at constant temperature, this factor does not enter.

Our thanks are due to Dr S. G. Barker, and to Mr R. S. Whipple, for their kind help and provision of facilities during the development of this instrument.

A LABORATORY MOVING-IRON INSTRUMENT.

BY E. H. W. BANNER, M.Sc., A.M.I.E.E., A.INST.P.

[*MS. received, 17th March, 1927.*]

ABSTRACT. A sensitive A.C. voltmeter and milliammeter is described and its performance analysed. The moving system is a double repulsion type, using mumetal for the irons, and constraining strips in place of a spiral spring. No pivots are used, and readings taken for small changes of deflection should be of a high order of accuracy. The instrument has detachable coils, so that various ranges may be obtained, and by the addition of series resistances and shunts the ranges could be increased, although this is not recommended, as one of the principal advantages of this type of instrument is its very low consumption. The ampere-turns are 30, and thus about one-tenth of the usual pivoted instrument, and the power consumption about one-hundredth. The watts are 0·018 for full scale of 53°.

THE power consumption of the usual commercial moving-iron ammeter or voltmeter is such that measurements on low-power circuits are usually precluded, on account of the great alteration to the circuit caused by the connection of the instrument. It was hoped to make an instrument of the moving-iron type having a power consumption of much less than the usual, which may be taken as 1 to 3 watts. The instrument made and described is not perfect, but it so far shows how the design is practicable as to be considered a successful attempt to produce a low range A.C. instrument for power frequencies. The instrument differs little in principle from any moving-iron instrument.

The weak control is obtained by means of a suspension, instead of a spiral spring, and a similar strip at the foot constrains the movement from motion other than a rotational one, and also makes the instrument independent of accurate levelling. In the present instrument it ensures portability with reasonable care, as no clamp is fitted. By this means pivot friction is eliminated.

The repulsion type was chosen, and in order to produce a true couple on the suspension the irons were duplicated along a diameter. There are thus a total of four irons, two fixed and two moving. The instrument has a mirror for working with a distant scale. A pointer and scale are also fitted, but the short pointer length and limited scale render this useful for rough measurements only.

No fixed coil is fitted, but the construction allows for one of a number of bobbins to be slipped over the suspension piece into position. In this way the instrument may have various ranges. Two coils only are provided at present, and the calibrations performed with one. The other point of departure from standard practice is in the use of mumetal for the irons*

With an ordinary repulsion-type movement the theoretical maximum scale arc obtainable is 180°. Actually this cannot be fully realised. With the employment of a double repulsion system the maximum theoretical angle is halved. With this particular instrument 53° is the scale arc, as with the coils used this corresponds to a multiple of 10 in current. The ampere-turns for this deflection are 30, which is $\frac{1}{10}$ of the normal (about 200–400) and the power consumption 0·018 watt, which is about $\frac{1}{100}$ of the usual. The employment of this instrument in low-power circuits therefore causes rather less alteration to the circuit than would a pivoted moving-coil instrument in a D.C. circuit.

Considering the attraction and repulsion types, it would appear that the latter would have a higher inductance in the zero position of the movement, whilst the attraction type, having

* Since this instrument was made mumetal has been used by Messrs Edgcumbe and Ockenden. *J.I.E.E.* 65, p. 553, in a moving-iron instrument.

very little of the iron in the magnetic field, would have a low inductance. It is not surprising to find, therefore, that the change of inductance, which is proportional to torque, is low for this instrument, having a double system of irons. Actually it was measured to be 5 per cent. with the coil used for the main calibration.

The inductance was measured at different scale readings and a table is appended.

Bridge test at 400 ~

Deflection	Inductance henry
Coil only	0·157
0	0·234
5°	0·235
10	0·238
20	0·242
30	0·245
40	0·247
50	0·249
60	0·250
0 cover off	0·257
60	0·270

The working scale is about 50°, and the electromagnetic efficiency is thus 5 per cent. Details of the coils are:

(1) 3000 turns.

$R = 161\ \Omega$. $X = 78{\cdot}5\ \Omega$ at 50 ~ at 10°.

$L = 0{\cdot}157$ H (with no iron). $Z = 180\ \Omega$ at 50 ~ at 10°.

$L = 0{\cdot}238$ H (at 10° deflection).

(2) 300 turns.

$R = 1{\cdot}77\ \Omega$. $L = 0{\cdot}0015$ H (with no iron).

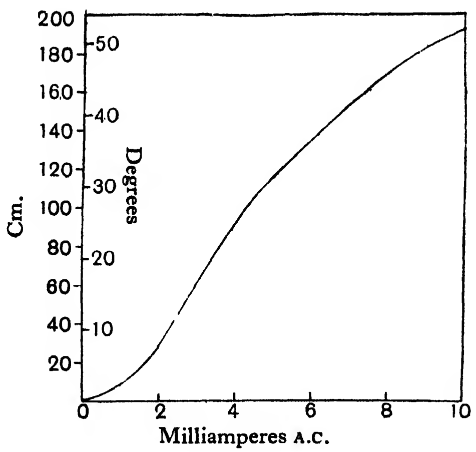


Fig. 1

Fig. 1 shows the calibration as a milliammeter with the 3000 turn coil. With a reflecting scale at a metre distance a half-metre scale will only read to a little over 2·5 mA, so that very small currents may be read. To read the full deflection a curved scale of nearly 2 m. length is required, at a distance of 1 m., or alternatively a shorter scale and more coils may be used. It is an advantage to have the current or the voltage a multiple of 10 so that shunts or resistances may be added to alter the ranges simply. At 50 ~ full scale is obtained with 10 mA, 1·80 volts. As a voltmeter this corresponds to a resistance of 180 Ω per volt, which is highly desirable for small-power circuits.

Calibrations were made with different initial angles between adjacent irons. The best shape of scale was obtained at an initial angle of 10°, zero being considered as when the two sets of adjacent irons are touching. For this reason the calculation of the electromagnetic efficiency is taken as the variation between 10° and 60°. The torque, calculated from the constants of the phosphor-bronze strip used, is about 0·03 gm. cm. for full scale. The approximate weight of the moving system is 0·8 gm., so that the torque/weight ratio is 0·038. Time to come to rest on switching on full scale current is 40 sec. The hysteresis error on D.C. is fairly large, probably due to the fact that the irons were not annealed after cutting and spot-welding*. The mean of reverse readings on D.C. agrees fairly well with the A.C. reading. The periodic time with the suspension fitted is 2·7 sec. Other suspensions were tried and the present one adopted as the best compromise between sensitivity and stability of zero.

Design

Fig. 2 shows a $\frac{3}{8}$-scale drawing of the essential parts, and Fig. 3 is a plan. The suspension is phosphor-bronze strip of size 0·254 mm. × 0·0127 mm. (or 0·01 in. × 0·0005 in.). A vane of thin aluminium, of length nearly equal to that of the bobbin, and width slightly less

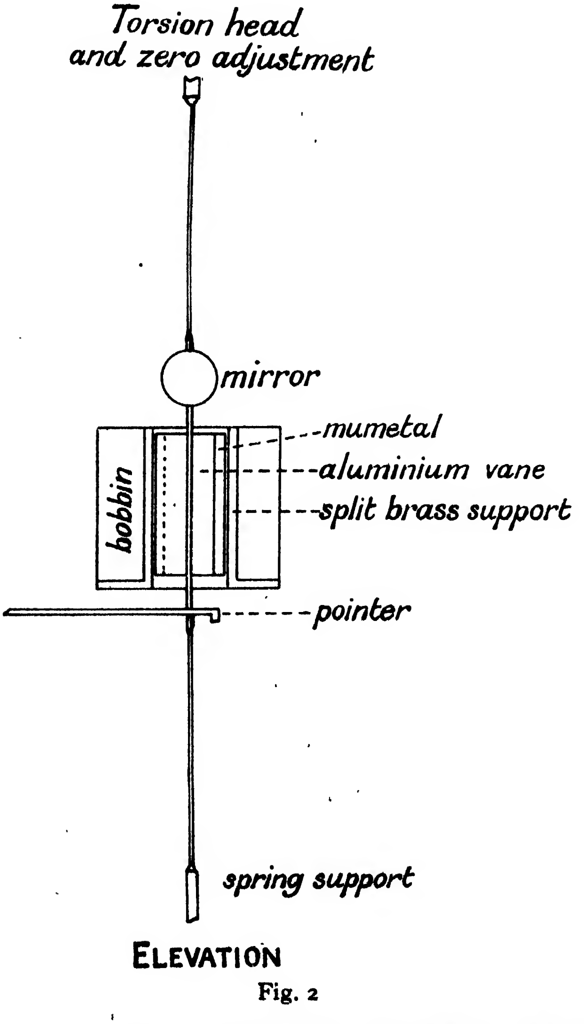


Fig. 2

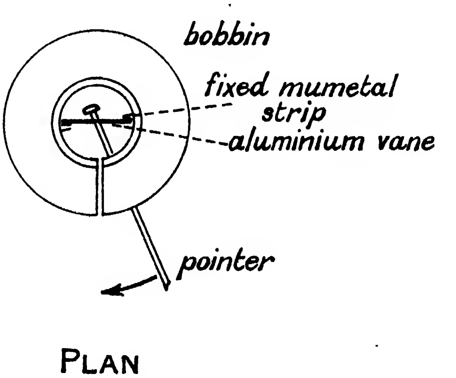


Fig. 3

* Since this instrument was made the author has been informed by several manufacturers that mumetal in a repulsion instrument is less satisfactory than in one of the attraction or single-iron type.

than the internal diameter of the brass frame holding the bobbin, carries a strip of mumetal 28 mm. × 2 mm. × 0·25 mm., spot-welded at each extremity. This vane acts as a damping vane as well as a support for the moving irons. The fixed irons are fitted in slots in the brass supporting piece, and are of similar dimensions to the other strips. The brass support for the coil and fixed irons is split down its length so as not to act as a short-circuited turn. This tube has an extension upwards to hold the top ebonite piece carrying the torsion-head and

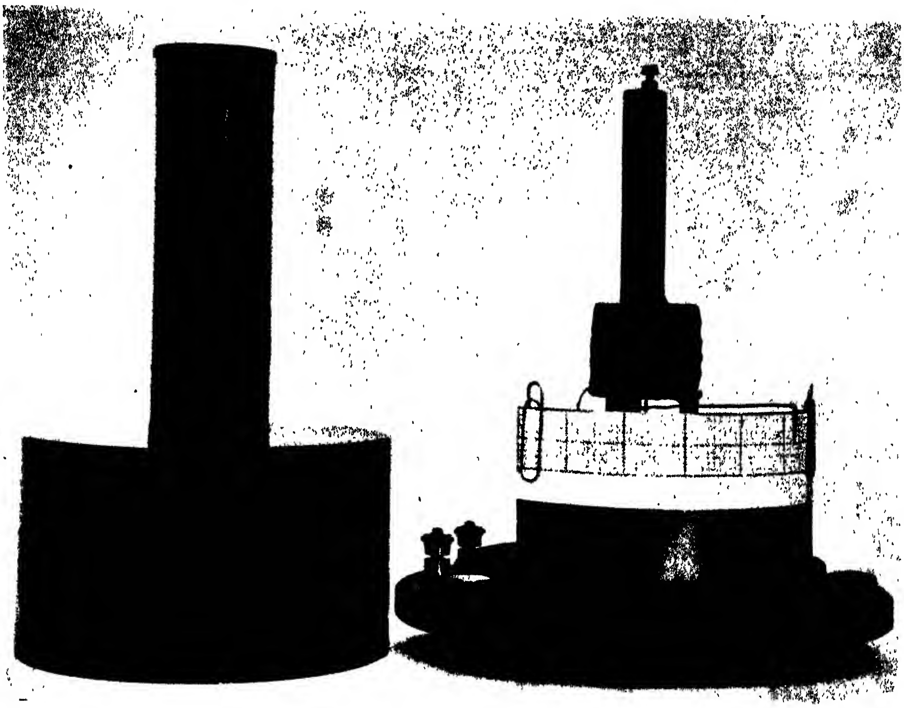


Fig. 4

zero adjustment. Its flange is screwed to three brass pillars which are screwed at their lower ends to the ebonite base.

The cover is of brass, lined with sheet iron, to shield the movement magnetically from moderate stray fields. As this type of instrument is not so susceptible to stray fields as a moving-magnet galvanometer, for example, an elaborate shield is not required.

Fig. 4 gives a general view of the instrument and cover.

Finally acknowledgement is made to Mr Seager, of Wembley, for the manufacture of the instrument and assistance in the mechanical design details.

NEW INSTRUMENT

A UNIVERSAL MILLING AND SHAPING MACHINE

Following a recent reference in this *Journal* to British instrument making lathes, the following description of a machine tool developed in this country to meet the needs of their own work has been received from Messrs Cooke, Troughton and Simms, Ltd., Broadway Court, Westminster, S.W. 1. The machine is described in full in their leaflet No. 512, and is illustrated in the accompanying Fig. 1.

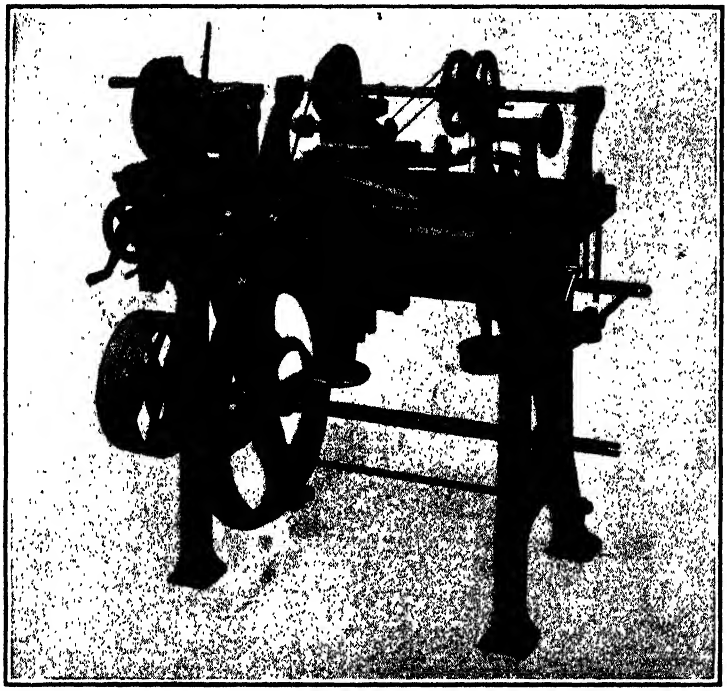


Fig. 1

A Machine Tool for Instrument Work

The evolution of this combination machine tool is spread over the past 60 odd years, during which period of time Messrs T. Cooke and Sons, Ltd., Buckingham Works, York (now Cooke, Troughton and Simms, Ltd.) gradually developed its features to meet the requirements of their production—embracing the manufacture of scientific and optical instruments and apparatus (both large and small), ordnance gear, such as range-finders, fire control gear, gun-sights and so forth. Such work calls for the highest possible accuracy and presents many difficult machining operations. To cope with the latter special attachments for lathes and machine tools were designed from time to time, and with the passage of years these attachments became standard features until they were combined in the machine tool under review. About a score of these machines are in regular use in the makers' own factories, where they are held to be indispensable. It might be mentioned that such a combination tool is in effect a universal jig, equally useful for a special job or for repetition work where accuracy and despatch are required. Many a tool-room has felt the need for such a tool.

From Fig. 1 it might be judged that this machine is intended to be used as a lathe, but the only occasion when actual turning is done on it is when a mandril or chuck is to be trued up to receive the work it is intended to carry. For this purpose the hollow mandril shown in Fig. 2 is revolved by hand—note the wooden handle fixed to the worm wheel which is attached to the mandril. The latter, to fulfil its function in the dividing head, is very accurately made, and to use it for mere turning would not be appropriate. On the

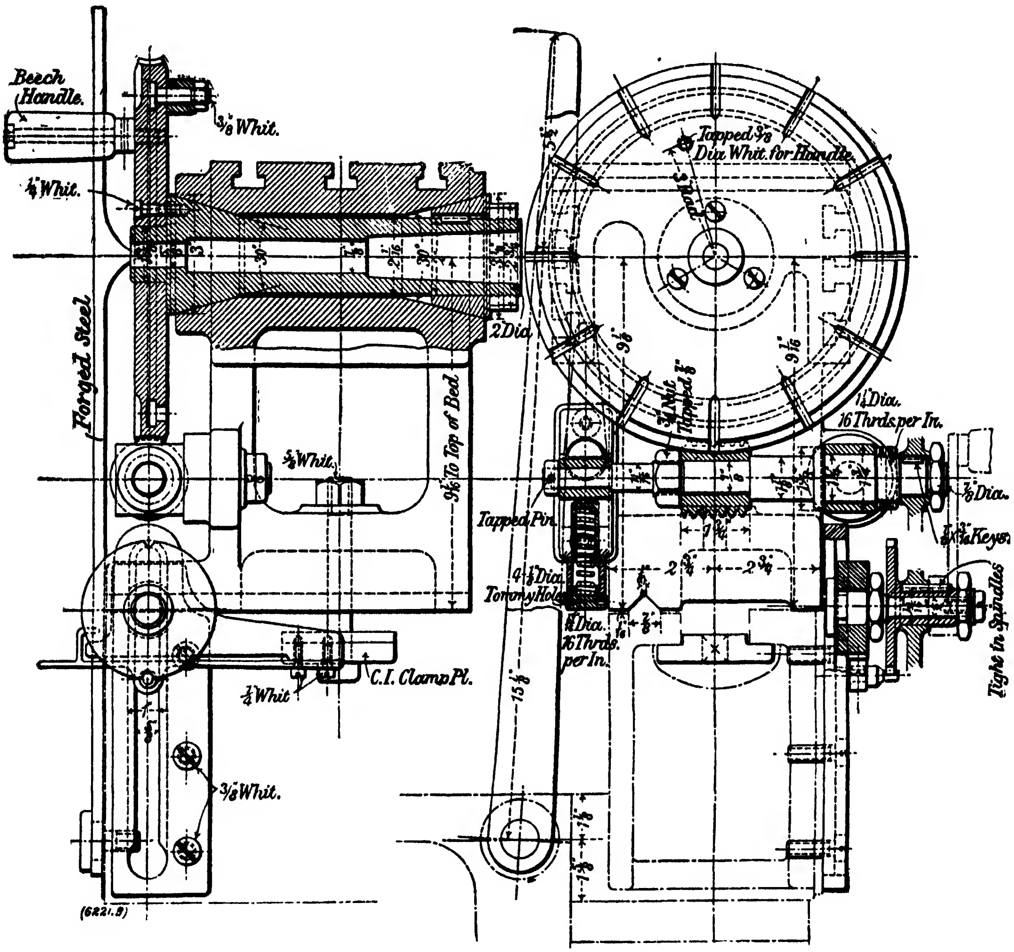


Fig. 2

other hand, the following list gives some idea of the wide variety of work, where accuracy and output are prime considerations, that can be readily undertaken on these machines:

(*a*) Small pieces of almost any shape can be machined by means of rotating or planing cutters.

(*b*) Precise drilling such as division plates; holes can be drilled at any angle.

(*c*) Cutting fine-toothed racks, pinions, and small spur, bevel and worm wheels.

(*d*) Profiling irregular shapes to a former, where great accuracy is called for, as in cams.

(*e*) Dividing circles up to 12 inches in diameter, or straight scales, with various lengths of division lines.

(*f*) Special attachment allows spirals and helicals to be cut.

The work may be in cast iron, steel, gunmetal, wood, ebonite, etc.

The work to be dealt with can, as required by circumstances, be:

(1) Attached to main mandril, or faceplate attached thereto.
(2) Clamped to vertical and horizontal faces of headstock.
(3) Clamped to the horizontal bed.
(4) Swung between centres, 9 inches high.

Spirals can be cut by connecting the lead-screw with the worm and worm-wheel of the fast-head through suitable gear wheels.

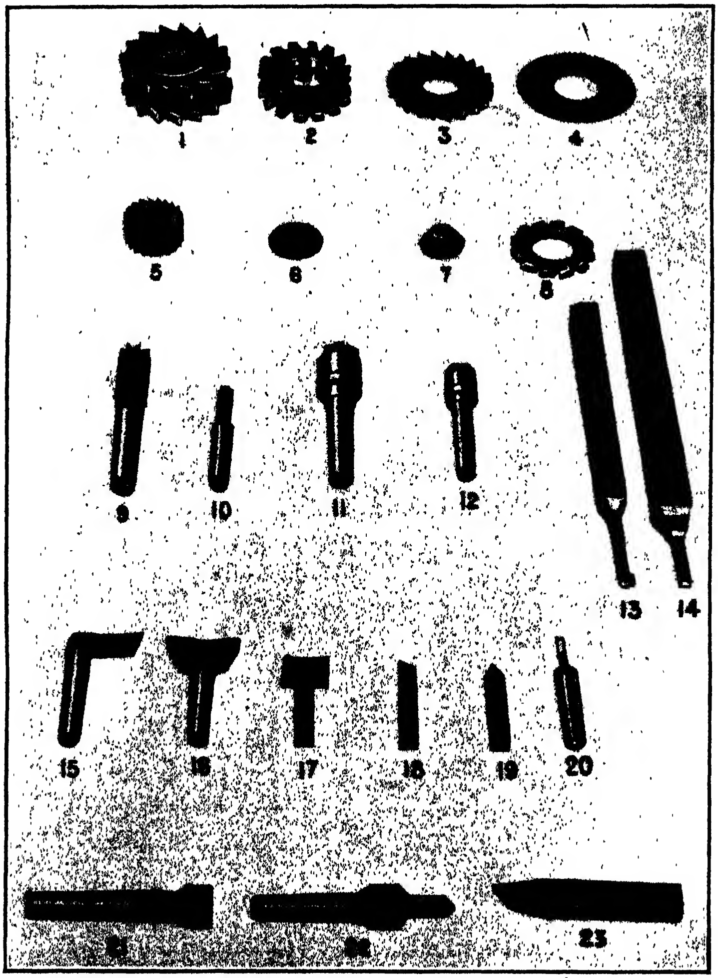


Fig. 3

The machine is self-contained (requiring no separate countershaft), and has fly-wheel shaft with fast and loose pulleys with striking gear. The back shaft runs on ball bearings and has cord-tightening pulleys for high-speed cutter-driving, and grooved driving cones giving a variety of cutting speeds. A fly-wheel pulley drives the back shaft by gut-belts, this shaft also furnishing the motion to the milling cutter or other rotary tool used.

The compound slide-rest is provided with vertical slide for elevating the cutting tool to a suitable height by means of a screw; top slides are operated both by screws and hand levers. The slide rest is capable of being turned to any horizontal angle and clamped there.

Normally a bed 3 feet long is found sufficient; the top and front-side faces are planed

and scraped; and the bed is supported on two cast-iron A frame legs. An accurately cut guide-screw traverses the slide as required. Mounted on the bed are fast and loose heads, the former being a work-table having vertical and horizontal Tee grooves for attaching stops and small articles to be machined. In the fast (dividing) head is fitted a hollow mandril with draw-in collets; arbors have nozzles screwed $1\frac{1}{4}$ inches diameter with eight threads per inch. An accurately cut cast-iron worm wheel and steel screw for circular dividing, with the necessary index plates are also provided. Stops provided to all slides for interchangeable work.

Fig. 3, illustrating some of the cutters and milling tools used with the machine, will particularly interest those readers who are actively engaged in the manufacture of scientific instruments.

LABORATORY AND WORKSHOP NOTES

SEMI-REFLECTING SURFACES. By INSTRUCTOR CAPTAIN T. Y. BAKER, F.Inst.P., R.N.

In a short note in the October number of the *Journal* on a method of testing the accuracy of the 90° angle of a roof prism, Dr A. Biot mentioned the advantages of using a semi-silvered surface for the purpose of introducing a collimated beam into the optical system. There are attendant disadvantages. The surface silvering is very liable to damage by abrasion, and unless kept, when not in use, in a desiccated vessel, rapidly tarnishes.

Ideally, the semi-silvered reflector transmits and reflects in equal proportions. In practice, it is difficult to attain equality, and in any case, the division is not "fifty-fifty" but more like "twenty-five-twenty-five," the remainder being lost. Consequently, by the time the collimated beam reaches the examining telescope, the intensity of the beam (making no allowance for loss in the prism) has dropped to 6 per cent. of its original value.

A better figure can be obtained if a plain unsilvered parallel plate of glass be used, set, possibly, at a finer angle to the telescope axis.

The surface reflection for an angle of incidence i with the normal, is, by Fresnel's formula,

$$\frac{1}{2}\left[\frac{\sin^2(i-i')}{\sin^2(i+i')}+\frac{\tan^2(i-i')}{\tan^2(i+i')}\right],$$

where $\sin i = n \sin i'$, n being the refracted index.

Denoting this quantity by α, we see that, of a unit quantity of light striking the first surface of a glass plate, α is reflected and $1-\alpha$ transmitted. Of the latter part $\alpha(1-\alpha)$ is reflected at the back surface and of this again $\alpha(1-\alpha)^2$ emerges from the front surface and $\alpha^2(1-\alpha)$ is reflected back. Proceeding in this way, we find that if the plate is perfectly clean on both sides, it reflects $2\alpha/(1+\alpha)$ and transmits $(1-\alpha)/(1+\alpha)$. Hence on return of the reflected beam to the plate, the total proportion that passes through to the telescope is $\dfrac{2\alpha(1-\alpha)}{(1+\alpha)^2}$, a quantity which has a maximum value of one-quarter when α equals one-third.

To obtain this maximum when the refractive index is 1·5 the angle of incidence must be about 78°, though this angle is smaller with a higher value of n. An angle of incidence of 45° with the normal results in $8\frac{1}{2}$ per cent. being received by the telescope; at 60° the figure is increased to nearly 14 per cent. and at 65° to 17 per cent.

The unsilvered glass plate can be kept clean, and when used at an angle of 60° to 65° is undoubtedly a more useful piece of laboratory apparatus than the semi-silvered reflector.

Dr Biot, at the beginning of his note, stated that a roof always needs touching up by hand, in order to obtain accuracy in the 90° angle. The tolerance of "quelques secondes" is not very definite, but presumably some four or five are intended. It may be of interest to the readers of the *Journal* to know that, in a set of prisms made by a British firm, it was found possible to polish twenty-four 90° angles in a block, and to test them while still on the block by an interference method, the angles being all within 2″ of 90°.

THE MOUNTING AND PREPARATION OF FINE WIRE SPECIMENS FOR PHOTO-MICROGRAPHY. By H. GOLLOP, B.Sc., A.I.C.

THE preparation (grinding and buffing) of sections of very fine wires or other small objects whose microstructure is to be examined and photographed is frequently difficult. The difficulty is increased when the sample is resistant to most etching reagents, for in that case the use of a low melting alloy as embedding agent, to facilitate handling, is generally objectionable.

A simple, convenient and (to me) original method of mounting and preparing such samples is as follows. A small wooden cube is treated on one roughened face with a thick layer of "Formite" syrup (the liquid form of Bakelite compound) and the wire is dropped into this mass. The whole is then heated in an oven at 110° C. for at least four hours. On removal from the oven and cooling the Formite has set to a hard amber-like mass, which adheres closely to the wood. This mass can be buffed down to the sample.

The fact that the compound is unattacked by most reagents enables the sample to be etched very conveniently. Electrolytic etching of the sample is facilitated by the fact that the compound is an excellent insulator. The method readily permits of the preparation of sections of such objects as corroded or encrusted wires, whose brittle outer layers can often be examined in position.

A SIMPLE SAFETY SLIPPING DEVICE

EVERY mechanic knows that a band brake like the one shown in the figure will only grip satisfactorily when running in the direction of the arrow *A*. It is not so generally appreciated,

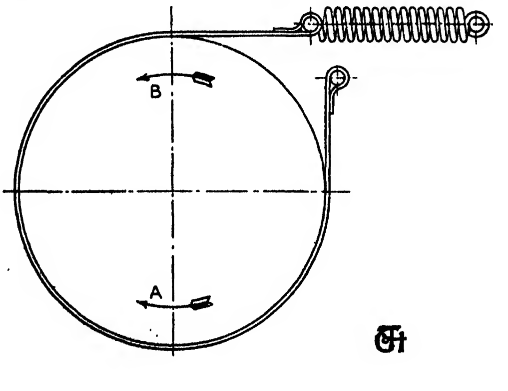


FIG. 1.

however, that, when used in the reverse direction (that of the arrow *B*), the brake will hold so long as the driving torque does not overcome the pull exerted by the spring, the drum not slipping until this is exceeded.

Used in this way, such a brake forms a simple overload release much kinder in action than the more common spring loaded claw clutch device. Fig. 2 shows how such a slipping device might be incorporated in the driving pulley of a machine. Here the driving pulley *A*

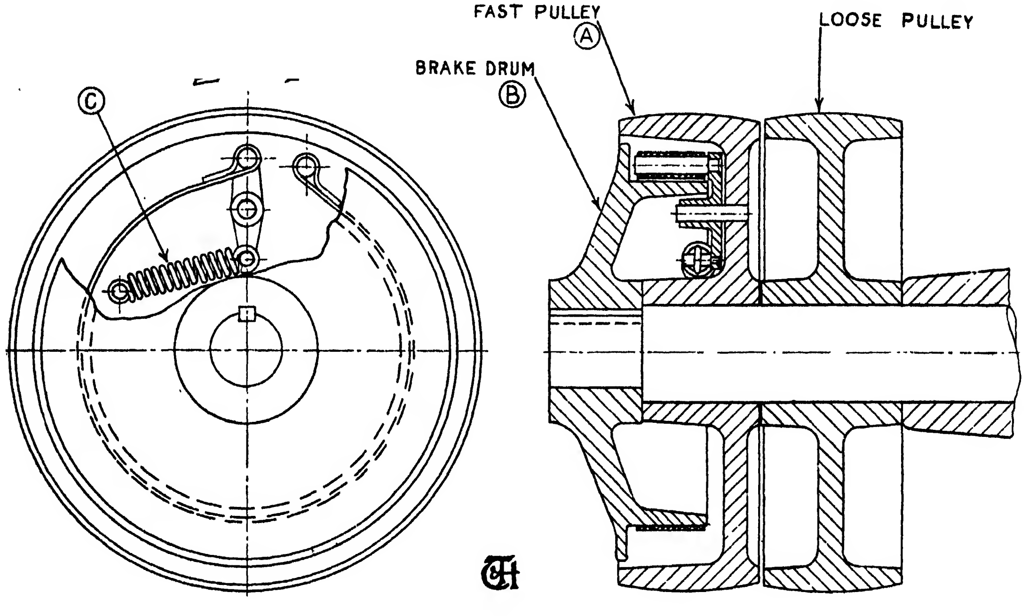


FIG. 2

is free on its shaft, the drive being by means of the band brake, which grips on the brake drum *B* which is keyed to the shaft. The "slipping torque" is controlled by the spring *C*, which is so adjusted that the driving pulley slips when the opposing torque exceeds a predetermined value.

THE TAYLOR-HOBSON RESEARCH LABORATORY,

LEICESTER.

CONTEMPORARY PUBLICATION

Zeitschrift für Instrumentenkunde

November 1927.

The Ring Photometer. G. I. Pokrowski of the Moscow Technical Institute describes a simple form of photometer for determining the light distribution in different directions from a source. The lamp is surrounded by a ring, the inner surface of which is bevelled at about 45° so that if it were polished the light would be reflected as an annulus parallel to the axis of the ring. The surface is however whitened with a matt surface, and a photograph of it is taken by a camera directed along the axis, so that the ring appears as an annular strip and the variations of illumination at different angles can be measured from the density of the negative, with the help of a graded comparison strip which is photographed on the same plate. The writer points out that the method is especially valuable in the

case of arc lamps or other unsteady sources, as the camera may be stopped down, so that a long exposure can be given which averages out fluctuations. Other arrangements of the ring for dispensing with a separate camera are described.

A New Form of Torsion String Electrometer. Prof. Eligro Perucca of Turin describes an electrometer of the Lindemann type in which the moving system is entirely of gilded quartz fibre. A vertical fibre is mounted on springs between two supports which are simultaneously rotatable, so as to provide for zero adjustment without torsion; and to the centre of this fibre a second fibre, bent in the form of a narrow rectangular loop with straight vertical end, is attached so as to swing like a skeleton vane. The ends of this loop project on the opposite side and enable it to be balanced, and the loop swings between two vertical gilded metal plates mounted on micrometer screws and forming the "quadrants." A reading microscope with a magnification of 100 is focussed on the vertical end of the loop.

With a torsion fibre of 0·007 mm. and a loop fibre of 0·02 mm. diameter, 20 mm. separation and 16 volts between the plates (8 volts above and below the loop potential) a sensitivity of 0·005 volts per eyepiece scale division has been obtained for a magnification of 100, but a magnification of 500 is possible with this instrument. The deflection was stable over the whole range of the scale (± 50 divisions) but not strictly proportional. With this sensitivity the instrument is overdamped by the air damping of the loop alone. It is easily set up and appears to remain very constant. Messrs Carl Leiss of Berlin-Steglitz have taken up its manufacture.

The Use of Perforated Card Machines in Climatology. The use of perforated cards for recording and treating statistical records is now becoming general, and Dr L. W. Pollak of the University of Prag contributes an interesting article on their application to meteorological data, with a description of the perforating and counting machine of the Powers Accounting Machine Co. of New York.

Scientific Kinematography. A form of kinema-camera specially designed for scientific investigations has been designed by the Askaniawerke A.G. of Berlin-Friedenau and is described by Messrs H. Friess and W. Ewald of that company. They point out that motion pictures owe their origin to the scientific investigations of Muybridge in 1877 on the movements of animals, and that although their popular application has overshadowed this purpose, they are now being increasingly used for scientific and technical research. The camera described is solidly made and is intended for the normal speed of 16–18 pictures per second with a variable rotating shutter, the aperture of which can be varied to give exposures between $\frac{1}{30}$ and $\frac{1}{225}$ sec. It is provided with a telescopic finder and range measurer and graduated vertical circle. Modifications for higher speed working are described and several examples of scientific kinematography, including the growth of bacteria, are shown. An amusing but very practical detail is the question "Ist schon geölt?" ("Is it oiled?") which strikes the eye when the camera is opened.

REVIEW

The National Physical Laboratory. Report for 1926. H.M. Stationery Office. Pp. 260. Price 7*s*. 6*d*.

(*Continued from page* 460)

AERODYNAMICS DEPARTMENT

A one-foot wind tunnel has been fitted up as a high speed tunnel for tests on small measuring instruments. Air speeds of 140 ft. per second can be obtained, using a 5 H.P. motor. The variation of wind velocity throughout the tunnel was measured by the deflection of a very small square plate held on a stretched torsion wire, the plate being perpendicular to the wind direction. The

flow was found to be very steady even without the usual honeycomb wall, and this is attributed to the use of a diverging cone at the exit end of unusually great expansion area, whereby the formation of eddies is discouraged.

Slow speeds of the order of 1 ft. per second are produced by fitting a baffle plate pierced with small holes at the entrance end of the tunnel, and these speeds are measured indirectly by observing the pressure drop across the baffle.

A hot-wire velocity meter has been made in standard form: it consists of four platinum wires of 0·001 in. diameter. Opposite pairs (one pair lying in a horizontal, the other in a vertical plane) are inserted in turn in the adjacent arms of a Wheatstone bridge circuit, and the instrument is rotated till a balance is obtained. The wires are by this means inclined symmetrically at a small angle to the local direction of flow, the components of direction being indicated on horizontal and vertical angle scales. Determination of speed is then made with the instrument in this position by an alteration of connections such that any two wires are placed in series to form one arm of the bridge, with standard resistances in the remaining arms; wind speeds above 20 ft. per sec. may be measured and directions can be determined to 0·05°.

Slow motion of flat plates. Experiments have been made on the fall of small square and circular flat plates through water and various oils. The resistance coefficient can be calculated from knowledge of the densities of the materials used and the speed of steady descent—in this way the transition stage is being investigated between the extremely slow motion contemplated in Stokes' theory and the high speed regime of ordinary aeronautical problems.

Spinning of aeroplanes. This report will shortly be published in book form. The chief conclusions are that the characteristics of an aeroplane which may lead to serious danger of failure to recover from a spin are (1) small stagger of the biplane cellule, (2) controls of inadequate area fitted at the tail, especially behind a body of wide and deep cross section, (3) the centre of gravity unduly far back, (4) weights distributed widely along the body so that its moment of inertia about the lateral axis is large.

METALLURGY DEPARTMENT

Refractories. A special refractory for thermo-couple protectors and sheathing has been made, consisting of a lime-alumina mixture: it can be used up to 1700° C., is non-porous and is resistant to the corrosive action of certain molten metals.

Dental alloys. A comparison has been made of four somewhat similar intermetallic compounds, Ag_3Sn, Ag_2Zn_5, AuSn and Cu_3Sn. The behaviour of these substances as regards ageing and plastic deformations differs so strikingly that an X-ray examination has been made. The results indicate marked differences in atomic arrangement in the four compounds, and account for the facts that two of the compounds (Ag_3Sn and Ag_2Zn_5) show an appreciable degree of ductility within the crystal, although the substance as a whole is brittle owing to intercrystalline fragility, while the other two compounds show no sign of ductility even within the crystal.

Iron-manganese alloys have also been studied by X-rays. The addition of manganese at first increases the dimensions of the body-centred lattice of alpha iron. In an alloy containing 15 per cent. of manganese, however, traces of the face-centred cubic lattice of gamma iron become noticeable, and alloys containing 50 and 60 per cent. of manganese exhibit this type of lattice very clearly.

Nickel chromium alloys. It is now possible to melt these alloys *in vacuo* up to 18 lb., and to forge and roll them at temperatures of 1300° C. by means of an electrically heated "silit" furnace. With cast nickel-chromium alloys the creep stress at 800° C. increases with increasing chromium content, and it is probable that the alloys of higher chromium content will make it possible to produce a wrought material having properties superior to those of the best existing alloy.

Beryllium. In connection with the production of metallic beryllium, the preparation of fluoride electrolyte and of cathode metal has been continued steadily and considerable improvement has been introduced in the purification of crude beryllium liquors. Efforts have been made to produce beryllium of higher purity, with a view to eliminating, if possible, the lack of ductility found in the re-melted cathode metal already available. One method which has been tried is that of distillation or sublimation in the high frequency furnace under reduced pressure. The purified metal however shows no marked increase in ductility.

FROUDE TANK DEPARTMENT

Increased demands continue to be made for mercantile test-work and research on naval architecture and ship propulsion: the hours of work in the Tank are now from 7.45 a.m. to 9.0 p.m., but even this extension has proved inadequate for the investigations in hand. Owing to the specialised character of the work it is impossible to review it in a satisfactory way and reference should be made to the Report itself by those interested. R. T. B.

BRITISH INDUSTRIES FAIR

THE Department of Overseas Trade send the following list of firms exhibiting in the Scientific, Optical and Photographic Section of the British Industries Fair, which, as previously announced, takes place at the White City on February 20th to March 2nd, 1928.

AMALGAMATED PHOTOGRAPHIC MANUFACTURERS, LTD.
ACCURATE RECORDING INSTRUMENT CO., LTD.
S. ARNULL WATT AND CO.
BOWER ELECTRIC (1926), LTD.
CHAS. BAKER.
BRITISH ACOUSTIC CO.
CLAROCIT CO., LTD.
I. CALVETE, LTD.
C. W. DIXEY AND SONS.
DOWSING RADIANT HEAT CO., LTD.
ELLIS OPTICAL CO.
E. B. FRY, LTD.
FOSTER INSTRUMENT CO.
WM. GOWLLAND (1916), LTD.
GEM DRY PLATE CO., LTD.
HOWARD, RAWSON AND CO., LTD.
HOUGHTON-BUTCHER (GT BRITAIN), LTD.
WM. HARLING.
IMPERIAL DRY PLATE CO., LTD.
ILFORD, LTD.
JOHNSON AND SONS.
T. MERCER.
F. H. MARLOW.
R. W. MUNRO, LTD.
PEDESTROS, LTD.
T. A. REYNOLDS, SON AND CO.
ROSS, LTD.
W. F. STANLEY AND CO., LTD.
STIGMAT, LTD.
SHORT AND MASON, LTD.
SMITH AND ANCILL.
THORNTON-PICKARD MANUFACTURING CO.
UNITED KINGDOM OPTICAL CO., LTD.
WILSON WARDEN AND CO., LTD.
WELLINGTON AND WARD, LTD.
WRAY, LTD.
W. A. WEBB AND CO.
JAMES A. SINCLAIR AND CO., LTD.
ELLIOTT AND SONS, LTD.
ACME ART ASSOCIATION.
THOS. ILLINGWORTH AND CO., LTD.
J. LILLEY AND SON, LTD.
BETAX MANUFACTURING CO., LTD.
MOTOR STETHOSCOPE CO., LTD.
UNITED CHEMICAL ENGRAVING CO., LTD.

NOTICE TO SCIENTIFIC INSTRUMENT MANUFACTURERS

IN order to keep readers of the *Journal* in touch with the latest developments in scientific instruments, the Editor would be glad if all manufacturers of such instruments would keep him informed of all new instruments or important improvements in their productions as soon as they appear, either by sending him catalogues, pamphlets, or circulars concerning them, or in the case of important developments, by letting him have concise special descriptions of their construction and performance. Descriptions of light machine tools suitable for instrument work would also be appreciated.

ERRATUM. In the Laboratory Note on "Purification of Rare Gases and 'Clear Up' by Sodium," by Mr James Taylor (the *Journal*, November 1927, p. 455, tenth line), the word "oxygen" should read "nitrogen."

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